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APPLE GROWING IN PRINCE EDWARD ISLAND[1]

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There is still doubt concerning the actual discoverer of Prince Edward Island. Some claim that Cabot named it St. John in 1497. France assumed that it was discovered by Verazani in 1523. Jacques Cartier, however, wrote some very interesting notes when he landed on "The Island" on June 30, 1534. He mentions the land being "full of beautiful trees." They were so pleasing that he mentions going ashore four times in one day "to see the trees, which were marvellously beautiful and sweet-smelling. We found: cedars, yews, pines, white elms, ash trees and willows, and many other sorts to us unknown, but all without fruit." He found small fruits and mentioned: "white and red gooseberries, strawberries and black raspberries." Referring to the country he wrote: "This land is of the best climate that can possibly be, and very hot."

A French naval officer, Captain Doublet, obtained a grant of the Island in 1663 and held possession until 1700, but established no permanent settlements. French fisher folk from Normandy came in 1713 and started the first permanent settlement. These probably brought the first large fruit trees. Their numbers were increased by many Acadians from Nova Scotia who would also bring fruit trees. The population, after the fall of Louisburg, 1728, when several families moved to Rollo Bay, was recorded as 300.

The Island was permanently transferred to Great Britain in 1763. Captain Holland made a survey in 1764, and divided the Island into 67 lots or townships of 20,000 acres each. The British Government parcelled out this land by lot to army officers and others. Each grantee was to settle his estate at the rate of one person per 200 acres in 10 years. The tenants held their land by leasehold. Settlers came from England, Ireland, Wales and the Isle of Skye. Lord Selkirk brought out 800 Scotchmen in 1803; 380 United Empire Loyalists came from the United States.

These hardy immigrants cut and burned the forests, stumped and cleared the land under great difficulties. The records show that they brought with them "fruit trees from their native land." The Royal Agricultural Society of Prince Edward Island was formed in 1845, and did much to improve agriculture and stimulate live stock breeding.

The Prince Edward Island Fruit Growers' Association was formed in 1896. The Lieutenant Governor, George W. Howlan took a great interest in fruit growing, and it was through his exertions and enthusiasm that the organization was started. Many other public men who were

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fruit growers took a very active part in the work of the Association. Some of these were Senator Donald Ferguson, Senator James E. Robertson, David P. Irving, M.L.A., Judge R. R. Fitzgerald and Judge F. L. Haszard. Rev. A. E. Burke was the first president and A. E. Dewar was the first secretary. They both held office for many years and gave a real impetus to the Fruit Growers' Assocation and the fruit industry. Prof. John Craig, Dominion Horticulturist, visited the Province in 1894 and in 1896. He spoke at a number of meetings, and assured the fruit growers that climate and soil conditions were very favourable for both large and small fruits.

The Prince Edward Island Legislative Assembly passed an act in 1900 entitled: "An Act for the Encouragement of Agriculture." Under authority of this act the Department of Agriculture was organized early in 1901. The Legislative Assembly gave a grant of $75.00 per year to the Fruit Growers' Association when formed. This was afterwards reduced to $50.00 per year and paid through the Department of Agriculture. This Department also included the Fruit Growers' annual reports with the departmental reports for the years 1902, 1903 and 1904.

Senator James E. Robertson, who had travelled with Sir William Dawson when the latter was making his geological survey of the Island in 1870 and 1871, quotes Sir William as follows: "I am surprised that there are not more apples grown on this island. The soil of your south-eastern section of the country is the best soil for apple growing on this side of Devonshire, England." Senator Robertson visited a number of old orchards about 1904. He mentioned the Creed orchard in Lot 59 that was planted with trees brought from Boston or Salem in 1800. The late Mr. Richard Westaway of Albion, "brought trees from Devonshire, England, and planted them on the banks of the Montague River between the years 1800 and 1810." As this was to be cider orchard, he brought a cider mill with him. The Clarke apple tree, planted in Lot 59 by two boys at the head of the grave of their mother who died in 1785 bore fruit until it was blown down by a storm in 1895. It was then 110 years old. An apple tree planted in Belfast by one of the immigrants that came out in the *Polly* was vigorous and bearing fruit at the age of 93 years. Senator Robertson stated he knew of other old specimens and believed he could locate an orchard planted by the French previous to the fall of Louisburg (1728).

Dr. W. T. Macoun, Dominion Horticulturist, speaking at a meeting of the Prince Edward Island Fruit Growers' Association at Charlottetown, December 20, 1904, said: "I believe you have possibilities for fruit growing here which are equal to if not superior to any other province in the land". . . . "The next point I would make is the site for the orchard. I believe Prince Edward Island is one great site for an apple orchard. Almost the whole province is suited for orcharding and the rest of it will do for cranberry growing. I think with these two industries the whole country should be covered."

The accompanying table, taken from the report of the Seventh Census of Canada, 1931, shows clearly the trend up to that time in apple production in Prince Edward Island.

TABLE XLI.—PRODUCTION OF FRUITS, 1880-1930

Fruit	Unit	1880	1890	1900	1910	1920	1930
Apples	Bushel	31,501	52,018	159,421	160,375	174,764	108,066
Pears	Bushel	—	71	279	773	311	262
Plums	Bushel	2,547	1,479	4,265	5,231	2,034	1,179
Cherries	Bushel	—	4,265	17,838	7,135	2,857	1,915

It will be seen from this table that there was a steady increase in apple production until 1920. Since that date there has been quite a decrease. The same report shows that apple trees of bearing age decreased during the period 1901 to 1931 by 26.77%, and that apple trees not of bearing age decreased by 40.11%. A total of 8,191 farms reported apple orchards in 1921, whereas only 6,657 reported apple orchards in 1931.

The reasons for this decline in apple production are not easy to determine. Commercial production had never developed to any extent because of poor shipping facilities. Farmers found other lines more profitable than fruit production. Seed production of potatoes and table stock production of both potatoes and turnips as cash crops have produced large revenues some years. For a number of years the silver fox industry was a real competitor with all other types of farming. In more recent years a strong demand has developed locally for both dessert and culinary fruit, and there has been an increase in planting of suitable sorts.

The Provincial Department of Agriculture planted an apple orchard of 190 trees at the Falconwood Farm in 1902. The original planting of 31 varieties was increased to 38 in 1903. Three trees of each variety were planted, and those believed to be most suitable were planted in larger numbers as follows: 28 Ben Davis, 23 Stark, 18 Wagner, 13 Baldwin and 10 Baxter. The trees were set 33 feet apart each way, with fillers of plums and pears in the rows east and west. Corn and roots were grown among the trees. Thirty Spy, 20 Ontario, 10 Tolman Sweet and 10 Sutton Beauty were among those added to this orchard in 1903. Five model apple orchards, one acre in extent with 40 trees each, were planted in 1902 at the following places: Lower Montague, Morell, Springfield, Kensington and Alberton. Later, additional model orchards were planted at Caledonia, Selkirk Road, Gowan Brae and Tryon.

Orchard meetings with demonstrations in pruning and spraying were given at the model orchards and at many other points throughout the Province by members of the Department, fruit inspectors from Ottawa and others. Much enthusiasm in fruit growing resulted. A co-operative Fruit Marketing Association was formed, and many apples were shipped direct to the British markets.

Two varieties of apples that originated on Prince Edward Island in the early days were Inkerman produced by Mr. John Robertson, Brudenell, and Dodd, produced by Mr. Thomas Dodd, Cherry Valley. The Inkerman came from the root of an imported tree that had died down. The Dodd came among trees imported from New York, and was first thought to be Smoke House.

At the Charlottetown Experimental Station about 100 varieties of apple trees were set out in 1910. These, besides the leading commercial varieties, included many new sorts to be tested for quality, hardiness and fruitfulness. The site chosen had a southerly slope, and a shelter belt of forest trees on the north and east. The soil, which was a sandy loam, had good natural drainage. It was very weedy and in a run out condition. The old sod was ploughed down in the summer of 1909. A dressing of 10 tons of barnyard manure per acre was applied and worked in during the spring of 1910. The ground was continually cultivated during the early summer and much couch and other weeds killed. On July 21, cover crops were sown and the whole area seeded out to clover.

From 1911 on, the orchard was sprayed regularly, pruned and handled so that the trees made satisfactory growth. In 1914 the first apple matured from a tree set in 1910. In 1915 five varieties produced fruit. Growth that year was reported slow, probably because of the heavy clay hard pan that underlies most of the section of the apple orchard. Many new sorts were added from time to time. In 1923 one dozen McIntosh were set in a row east of the former orchard.

The Station report for 1928 gave the following list of desirable varieties from which a choice could be made for planting in this province:

Summer varieties: Yellow Transparent, Red Astrachan, Crimson Beauty.

Autumn varieties: Melba, Duchess.

Early winter varieties: Wealthy, Scarlet Pippin, Schiawasse Beauty, Lobo, Alexander, Walter, Baxter, St. Lawrence, Wolf River.

Winter varieties: Ribston Pippin, Pewaukee, Tolman Sweet, Bethel, Northern Spy.

The 1929 report contained a list of distinctly inferior varieties. In the 1930 report there is a detailed list, stating number of trees of varietiy and date of planting, with remarks on hardiness, production, quality of fruit and suitability for planting on the Island. In the summary report for 1931-1935, published in 1936, a description and results secured from a grass mulch system for the apple orchard is described, undesirable varieties are listed and winter injury in 1933-1934 is described as affecting different varieties. The varieties then under test are given, showing those severely injured or killed, those with slight injury and varieties uninjured, whether the injury was evident that spring or within a year or two afterwards. This period gave all trees the most severe test since apples were planted at the Station. It is interesting to note that very little change in recommended varieties occurred even after this severe test. Summer varieties were the same, early autumn were the same, late autumn and early winter varieties had Hume and McIntosh added, and Schiawasse Beauty, Alexander, Walter, Baxter and St. Lawrence dropped. In winter varieties the dropping of Northern Spy was the only change. No further Station reports have been published, but in 1940 Farmers' Bulletin 97, Varieties of Tree Fruits for Prince Edward Island, was published by the Charlottetown Station. This bulleting presents a brief review of the common varieties of apples grown or offered for sale in the province, as well as a description of a number of newer varieties still on probation here or elsewhere, which

may be suitable for planting on the Island. On page 11 a list of varieties recommended for the home orchard is given. The prime requisites in making this selection were hardiness and quality of fruit.

Comparing this with previous lists, the summer and early autumn varieties still remain the same. Late autumn and early winter have Cortland and Atlas added, Gravenstein, Scarlet Pippin and Wolf River dropped. Brighton (a red sport of Pewaukee), Sandow, Lawseed, and Choate have been added, and Tolman Sweet and Bethel have been dropped from the list of winter varieties.

The Charlottetown Station issued in 1941 a booklet entitled The Production of Tree Fruits in Prince Edward Island. A brief synopsis, in so far as it applies to apple growing in the province, is given as the summation of this article on Apple Growing in this Province.

Apples can be grown quite successfully in the farm orchard or on a commercial scale, provided they receive proper care and attention. There has recently been a considerable increase in commercial plantings. There is a growing demand locally for high grade dessert apples, and Island apples have a preference when properly packed and displayed.

The apple orchard should be sheltered, particularly from the prevailing winds and occasional storms. A northern slope and satisfactory air drainage is desirable.

Unless natural shelter is available, windbreaks are essential. White spruce is one of the best trees for this purpose. The windbreak should be at least 50 feet to windward. Spruce trees, either alone or combined with deciduous trees, and in two or more rows, will prove effective. Use young, thrifty trees and allow as much soil as possible to adhere to the roots when the trees are being moved. Apple trees do best when planted in blocks by themselves 30 feet apart each way in rows.

The varieties mentioned previously in this article are recommended for the farm orchard.

Spring is the best time to plant apple trees in Prince Edward Island. If secured from nurseries too early for planting, dig a shallow trench, soak the trench with water and heel them in. Plant just as early as the soil can be worked satisfactorily. When possible, the land should be prepared two years in advance. A clover sod ploughed under, for a well manured hoed crop that is thoroughly cultivated makes conditions favourable for fruit trees.

Care should be taken to prevent the roots of the apple trees from becoming dry. In digging the place for the tree, put the top soil by itself. Allow enough space in the hole so that the roots may be spread without any crowding. Fill in the top soil first, shaking the tree up and down to settle the soil about the roots without any air spaces. Tramp the soil well about the roots as the hole is being filled. The tree should be about 1 inch deeper in the ground than it stood in the nursery. A small amount of peat may be placed about the roots, but putting manure or fertilizer anywhere near the roots should be avoided. Straw or trash mulches are very beneficial.

Broken or damaged roots should be removed when planting. Reduce the top in proportion to the roots lost by the tree by removal from the nursery. A central leader and four or five branches are plenty to leave on a young tree. Moderate pruning is recommended.

Young apple trees benefit from cultivation. It produces vigorous, healthy growth and reduces the period before the trees come into bearing. Such cultivation should cease early in July, and a cover crop of oats, buckwheat or rye will reduce moisture and available food and hasten the maturing of the wood to prevent winter injury.

Orchards may be grown in sod provided sufficient mulch is used in the system to keep down all other vegetation within an area equal to the spread of the branches. Manure or fertilizer should be used to produce vigorous growth. These should be applied before the trees bloom and should be spread well out, beginning several feet away from the trunk of the tree.

Once the framework of a tree is established by careful training and judicious pruning, very little further pruning is required until the tree comes into bearing. Older trees are pruned to admit thorough spraying and abundance of sunlight. Branches well placed and at right angles to the trunk should remain, and light pruning early in the spring should remove any sucker growth and small branches that interfere with others or prevent the sun from producing well coloured fruit.

Spraying is essential, and spray calendars and timely suggestions in local papers from agricultural workers provide the necessary information as to how to combat the insects and diseases that must be controlled to produce high quality fruit.

Winter protection for the trunks of apple trees against mice and rabbits is usually necessary. Building paper or wire guards properly placed are good insurance against these pests. Building paper is also recommended as protection for the young trees against sunscald.

PRUNING METHODS FOR BEARING PEACH TREES[1]

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Results reported by Marshall (4) and still further data presented by Ricks and Gaston (6) showing crop reduction by pruning live wood from bearing apple trees suggested to the authors the desirability of some experiments on pruning bearing peach trees. With these trees, it is common practice to prune more heavily than with apples and probably rightly so since, for a continuous renewal of fruiting wood, the peach is dependent on strong terminal growth rather than a spur system as in the apple. However it did seem that, when trees in the prime of their life but not yet fully occupying the land were making satisfactory growth, it might be unwise to reduce the bearing area and to force excessively long and late growths by heavy pruning. Because Palmer *et al.* (5) have just recently reviewed the literature on peach pruning it seems unnecessary to discuss it in this paper. These investigators themselves found that annual cutting back into one year wood delayed bearing and reduced per tree yields during the first ten years in the orchard.

PROCEDURE

In the spring of 1937 thirty trees at the Horticultural Experiment Station (designated "Vineland") and sixteen trees at the farm of F. E. Blackhall, near St. Catharines, were selected for pruning experiments. Both lots of trees were planted in 1933 and were therefore, entering their fifth year in the orchard at this time. In the first lot there were trees of three unnamed seedlings under test, 12, 9, and 9 trees of each and at Blackhall's all trees were of the Elberta variety. The unnamed seedlings included one early, one midseason and one late maturing kind. The planting distance was 18 feet × 20 feet (5.5 m. × 6.1 m.) in both orchards but the row under experiment at Vineland was an outside one with no competing trees on the east side.

Under each treatment there were the following annual wood removals: 1, dead, dying and very weak wood and low drooping branches (basic treatment); 2, same as 1 plus a heavy heading back of the extremities of all branches to a lateral arising from two year wood (Figures 1 and 2); 3, same as 1 plus about half of the laterals (smaller ones) on the one year wood (Figures 3 and 4). In the fifth year, 1941, a few large near-vertical branches were removed from the trees of all treatments. In this year also there were so few laterals on the 1940 wood that it became necessary, in order to partially maintain the system, to do further thinning of laterals on the 1939 wood. At Vineland, tree 1 was given Treatment 1; tree 2, Treatment 2; tree 3, Treatment 3, and repeating systematically down the row. At Blackhall's there were Treatments 1 and 2 only, 1 being on one row and 2 on an adjacent row.

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[1] Paper read at the Horticultural Group meetings of the Canadian Society of Technical Agriculturists at the Annual Meeting at Olds, Alberta, June 18–19, 1942.

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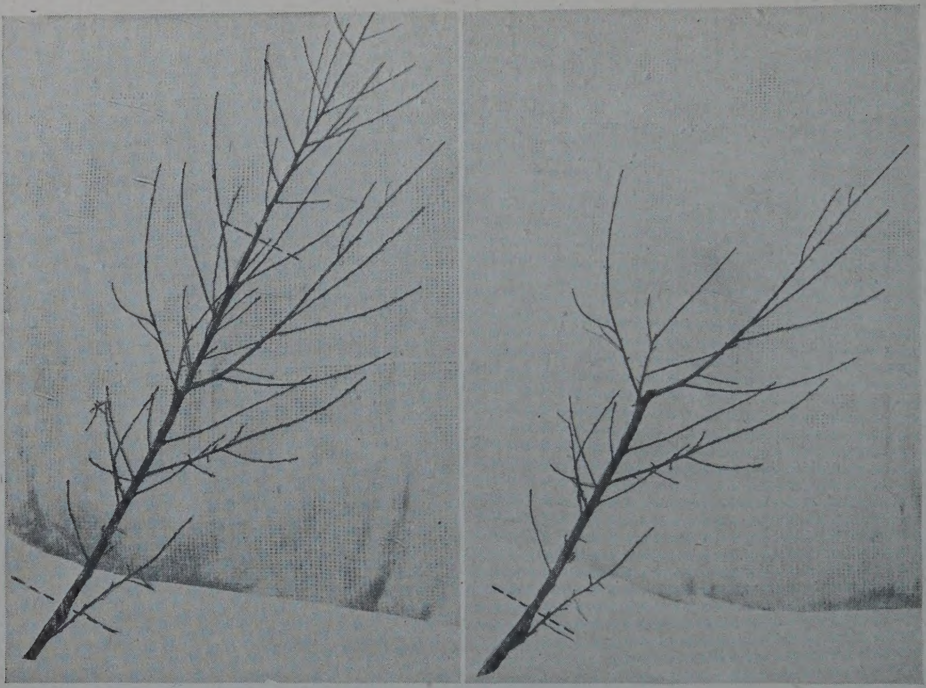
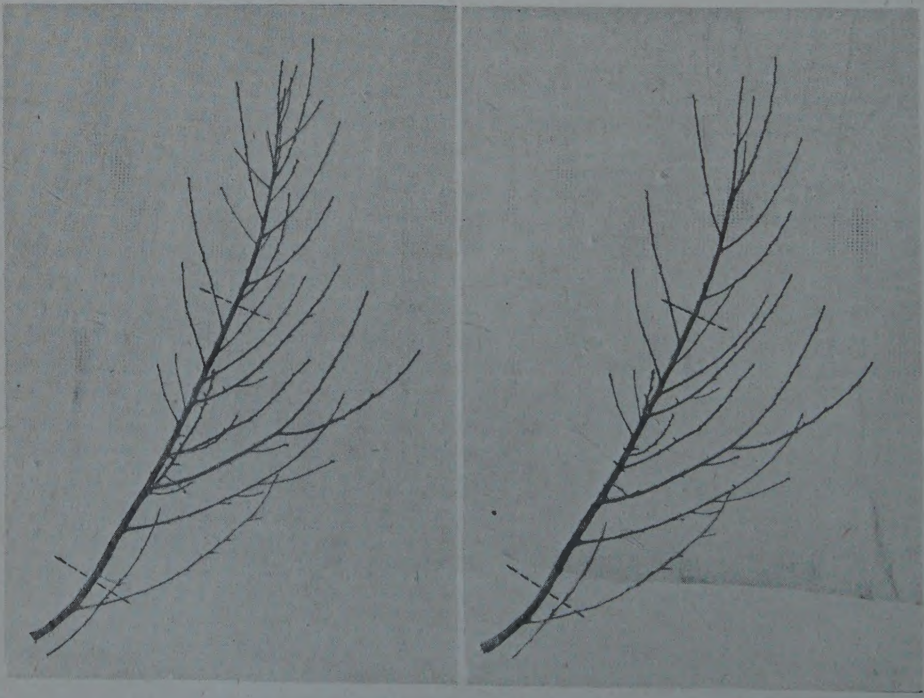


FIGURES 1 and 2. Branch from a five year old peach tree before and after being given Pruning Treatment 2. Broken lines mark divisions between one and two and two and three year old wood.



FIGURES 3 and 4. Branch from a five year old peach tree before and after being given Pruning Treatment 3. Broken lines mark divisions between one and two and two and three year old wood.

MEASUREMENTS

Trunk circumference measurements were taken in the spring of 1937 and each fall thereafter. Fruit yields for each tree were obtained at Vineland but it was possible to get only yields per treatment at Blackhall's. The crops were graded each year. In the first two years relative amount of prunings was estimated for each treatment but in the last three years actual weights were taken. In the latter period also more complete crop data was taken, including percentage of crop picked at first picking, percentage above No. 2 grade, and percentage picked while standing on the ground. To reduce variation in picking records, only those peaches which could be picked without pulling the branch down were counted as being picked from the ground. In 1940 and 1941 the time required for pruning and thinning each tree was recorded. In the fall of 1941 terminal growth measurements, 10 per tree were taken. Apart from trunk measurements, yield and grade of fruit, and height and spread of tree, this was the only other record taken at Blackhall's. Extreme widths and heights of trees were taken in the fall of 1941, the width being an average of east-west, and north-south measurements for each tree.

RESULTS

Tree Size and Rate of Growth

The average sizes of the trees under each treatment showed variation even before the pruning experiments were commenced (Table 1). This was particularly true of the Blackhall orchard where the headed trees averaged about 40% larger than the non-headed trees. To eliminate these size differences and thus facilitate interpretation, the growth rates on each lot of trees were determined and are presented in Table 2. These figures show a reduced growth rate for heavily headed trees.

TABLE 1.—AREA OF X-SECTION OF TRUNK (SQ. CMS.)

Treatment	Vineland		Blackhall's	
	April, 1937	Nov., 1941	April, 1937	Nov., 1941
1. Basic	54.4	240.7	41.4	191.8
2. Basic + heavy heading	51.1	202.9	58.0	216.8
3. Basic + lateral thinning	54.4	246.0		

TABLE 2.—GROWTH RATES*, 1937–41

Treatment	Vineland		Blackhall's	
1. Basic	32	odds† 10 to 1 (1 and 2)	34	odds 11 to 1 (1 and 2)
2. Basic + heavy heading	30	odds 73 to 1 (2 and 3)	28	
3. Basic + lateral thinning	33			

* By Geometric Mean formula and based on increase in area of x-section of trunk.

† Odds were determined by Student's method. They do not closely follow differences between treatments because of the inconstancy of variation within treatments.

Yield per Tree per Year

Heavy annual heading back reduced the yield of fruit when compared to the non-heading treatments (Table 3). At Vineland the differences in yield per tree between Treatments 1 and 3 were not significant.

TABLE 3.—YIELD PER TREE PER YEAR (LB.), 1937–31

Treatment	Vineland		Blackhall's*
1. Basic	160	odds over 9999 to 1 (1 vs. 2)	192
2. Basic + heavy heading	130	odds about 400 to 1 (2 vs. 3)	158
3. Basic + lateral thinning	157		

* Yields were not taken for individual trees and thus odds could not be determined.

Weight of Prunings

During the first two years relative weights of prunings were estimated at the Vineland orchard but during the last three years actual weights were taken, the averages of both being shown in Table 4. If the amount of dead wood varies with treatment pruning weights will be misleading to that extent owing to the desiccation of the dead tissue. However, in this experiment, the errors from this cause were not large. The *relative* amount of pruning under Treatment 2 is greater than indicated in Table 4 because of the smaller size of these trees (Table 1).

TABLE 4.—PRUNINGS PER TREE PER YEAR, VINELAND

Treatment	Estimate,* 1937–38	Actual weights (lbs.) 1939–41
1. Basic	5.0	8.6
2. Basic + heavy heading	6.7	13.5
3. Basic + lateral thinning	5.9	11.7

* Estimated on the 1 to 10 basis, not pounds.

Time of Fruit Maturity

Trees under Treatment 2 had the appearance of a high nitrogen condition which was further shown by a later maturing fruit and sometimes by a reduced amount of red surface colour. The retarded maturity is shown by the records on percentage of total crop picked at the first picking (Table 5).

TABLE 5.—PERCENTAGE OF CROP PICKED AT FIRST PICKING

Treatment	Vineland, 1939–41
1. Basic	56
2. Basic + heavy heading	44
3. Basic + lateral thinning	54

Percentage of Crop Picked While Standing on the Ground

One argument advanced for heavy heading of young bearing peach trees is that such treatment keeps them low, allowing for easier picking. Results obtained in these experiments tend to weaken this argument, for the differences in percentage of crop which can be harvested from the ground are small (Table 6). Taking into account the reduced crop under Treatment 2 (Table 3) a slightly greater *weight* of peaches was picked from the ground under Treatments 1 and 3. However, because the trees were taller, as will be shown later, there was undoubtedly higher climbing for some of the fruits under Treatments 1 and 3 than under Treatment 2. This was particularly true for the vertical or near-vertical branches which were not appreciably pulled down by the weight of the fruit crop. Balancing all the evidence it is doubtful if there was any appreciable difference between treatments in harvesting cost per basket of fruit. A better record on this phase of the experiment would have been obtained by time-of-picking records for each tree. This change is being made in a new pruning experiment commenced with younger trees in 1941.

TABLE 6.—PERCENTAGE OF CROP PICKED WHILE STANDING ON THE GROUND, VINELAND, 1939–41

Treatment	
1. Basic	38
2. Basic + heavy heading	44
3. Basic + lateral thinning	39

Grade of Fruit

Canadian peaches may be graded as Select (2½ inches and up), No. 1 (2⅛ inches to 2½ inches) or No. 2 (1⅞ inches to 2⅛ inches) when coming up to certain standards of colour and freedom from defects. Since most Ontario growers get the same prices for both Select and No. 1 these two grades have been grouped together in the records of this experiment. On this basis the figures are shown in Table 7. Even though an attempt was made to thin the peaches with regard to nearby leaf area the peaches from Treatment 1 were somewhat smaller than they were under the other treatments. Although Treatment 1 has given a lower percentage of the crop above No. 2 grade than Treatment 2, the actual *weight* per tree of the larger-sized peaches has been slightly greater, 93 lbs. for Treatment 1 and 87 lbs.

for Treatment 2 (See total yields in Table 3). There was a high proportion of No. 2 peaches under all treatments which can be explained by the fact that one of the unnamed seedlings in the experiment is naturally a small peach running very largely to No. 2 sizes. At Blackhall's the proportion of the crop above No. 2 grade was over 99% for both treatments.

Table 7.—Grading of peaches, Vineland, 1939–41

Treatment	Percentage of crop above No. 2 grade
1. Basic	58
2. Basic + heavy heading	66
3. Basic + lateral thinning	66

Height and Spread of Trees

There is no appreciable difference between Treatments 1 and 3 on height or spread of tree but trees under Treatment 2 are definitely less spreading and less tall (Table 8). These results corroborate the growth rate figures (Table 2).

Table 8.—Width and height of trees (metres), Nov., 1941

Treatment	Vineland		Blackhall's	
	Width	Height	Width	Height
1. Basic	6.3	4.6	6.2	4.8
2. Basic + heavy heading	5.5	4.1	5.5	4.4
3. Basic + lateral thinning	6.4	4.7		

Terminal Growth

In 1941 it was quite evident that the growth of trees under Treatment 1 and to some extent under Treatment 3 was becoming weak. Measurements of terminal growth taken in October verified this observation (Table 9). The growth under Treatment 1 and 3 is definitely below the desirable standards set by Cullinan (1), Johnston (3), and Palmer *et al.* (5) all of which are above 30 cms. These figures indicate then that these trees ought to be given heavier pruning or feeding or both to stimulate the development of longer and stronger terminal growths. Though some allowance should probably be made for reduction in growth due to abnormally dry conditions in 1941, the 1940 growth under Treatment 1 was evidently approaching the under-vegetative condition for it averaged only 29.7 cms. at Vineland.

Table 9.—Length of terminal growth (cms.), Oct., 1941

Treatment	Vineland	Blackhall's
1. Basic	16.5	14.2
2. Basic + heavy heading	32.3	29.2
3. Basic + lateral thinning	20.3	

Time of Pruning and Thinning

During 1940 and 1941 time of pruning and fruit thinning was taken for each tree. The average time for these operations per tree are given in Table 10. The order of increasing time for the treatments is 2, 1, 3. Using only the last two years of the experiment in timing pruning and thinning operations undoubtedly gives figures somewhat higher than would have been obtained had time been taken for the whole 5-year period but the time relations between treatments would probably have been similar.

TABLE 10.—TIME OF PRUNING AND THINNING PER TREE PER YEAR (MINUTES), VINELAND 1940–41

Treatment	Pruning	Thinning	Total
1. Basic	28	38	66
2. Basic + heavy heading	35	23	58
3. Basic + lateral thinning	54	30	84

Monetary Returns after Deducting Cost of Pruning and Thinning

After deducting the cost of the containers the average prices paid to the growers in the Vineland area during the 3-year period, 1939–41, was approximately 1.85 cents per lb. for Select and No. 1 and 1.20 cents per lb. for No. 2. No figures for cost of labour for the Vineland district are available but the figures for all Canada indicate an approximate cost of 20 cents per hour for the period of this experiment (2). However, as wages commonly run higher in intensive farming districts, 25 cents per hour has been used for labour cost calculations in this report. Using this figure and the data in Table 3 and 7 it is possible to show the probable returns per tree per year for the various pruning treatments (Table 11). This summary shows an appreciable reduction in returns from Treatment 2 but no significant differences between Treatments 1 and 3. To partially offset the present advantage of Treatments 1 and 3 the trees under these treatments now require relatively heavier pruning than trees under Treatment 2 in order to increase their vigour; but they are larger trees (Table 1) and this will tend to compensate for the heavier pruning required.

TABLE 11.—MONETARY RETURNS PER TREE PER YEAR BEFORE AND AFTER DEDUCTING PRUNING AND THINNING COSTS, VINELAND, 1937–41

Treatment	Cost of pruning and thinning		Returns
1. Basic	$2.52	.27	$2.25
2. Basic + heavy heading	$2.12	.24	$1.88
3. Basic + lateral thinning	$2.56	.35	$2.21

SUMMARY

This report deals with three pruning treatments given from the fifth to the ninth year inclusive in the life of a peach orchard. Under each treatment there were the following wood removals: 1, dead, dying and very weak wood and low drooping branches (basic treatment); 2, same as 1 plus a heavy heading back of the extremities of all branches to a lateral arising from 2-year wood; 3, same as 1 plus about half of the laterals (smaller ones) on the 1-year wood. In the fifth year of the experiment, 1941, a few large near-vertical branches were removed from all treatments. There were two experimental blocks, one at the Horticultural Experiment Station and another in a grower's orchard (Blackhall). At the latter place there were no trees under Treatment 3.

Under the conditions in the orchard at the Horticultural Experiment Station there was an appreciable reduction in per tree income for Treatment 2 but little difference between Treatments 1 and 3.

Compared to the others, Treatment 2 gave heavier pruning weights, reduced growth rate, longer terminal growths, delayed fruit maturity and sometimes less red surface colour at the same stage of maturity. Treatment 2 gave a tree from which a higher proportion of the crop but less weight of fruit could be picked while standing on the ground. Compared to Treatment 1 it gave a higher percentage of the crop but actually less weight of fruit above the No. 2 grade.

Treatments 1 and 3 have given trees with greater bearing area as shown by height and width measurements but these trees are now becoming weak in growth calling for heavier pruning through which some of the advantage of increased bearing area will be lost.

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THE DETERMINATE TOMATO AND ITS RELATION TO PRAIRIE HORTICULTURE[1]

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The need for a tomato variety which will ripen a relatively large number of good quality fruits has long been felt by prairie growers. Many failures in growing tomatoes successfully on the Prairies can be attributed to the planting of heavy vined indeterminate varieties which, without pruning or staking, often fail to ripen an appreciable quantity of fruits. While pruning and staking these types may result in earlier fruit and a greater quantity of ripe fruit, the amateur grower, particularly the farmer, may not be able to spare the time for this operation. Many commercial growers, under recent labour conditions, cannot afford to stake their tomatoes.

The use of determinate varieties solves this problem, for this type of plant does not require pruning and staking. It produces a relatively short vine with sparse foliage and with fruits exposed to the sun, so that they ripen readily. In order to compare some of the more recent determinate vined varieties with the standard indeterminates, special trials were conducted at the Dominion Experimental Station, Morden, Manitoba, during the 1940 and 1941 seasons in addition to the usual varietal trials. Similar trials were conducted at the North Dakota Agricultural Experiment Station, Fargo, and yield data are recorded in this paper in support of the general results obtained at Morden.

DESCRIPTION OF THE TYPE

The term "determinate", with reference to the tomato describes plants with so-called "self-topping" or "self-pruning" growth habit. Determinate vined varieties flower more profusely than indeterminates, because blossom clusters usually occur at every internode, thus being separated by only one leaf. In the typical indeterminate, blossom clusters occur at every third internode, being separated by three leaves. Thus for a given length of vine, the plant with determinate growth habit produces considerably more fruit than the indeterminate. In addition, after a certain amount of elongation, further growth is inhibited, and the stem often terminates in a flower cluster. The determinate plant thereafter expends its energy in ripening those fruits already set. The unpruned indeterminate, on the other hand, tends to produce fewer branches but continues terminal growth on all of them until frost. Its crop ripens more slowly than that of the self-pruning type, and at the end of the season tomatoes may be found in all stages of development, many of which will be too small to use, and the energy expended in their production thus wasted. In general, the ratio of fruit to total plant weight is greater in the determinate than in the indeterminate.

Due largely to the foregoing characteristics, the determinate variety is often earlier than the indeterminates. Currence (2) found a distinct

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tendency for determinate plants to ripen earlier than indeterminates, although there was no indication whether the results were due to the gene for growth habit or to other genes in the same chromosome.

DEVELOPMENT OF DETERMINATE VARIETIES

Until recent years the determinate type was used very little commercially. Yeager (7) first noted the possibilities of adapting the determinate type to prairie conditions. He crossed Cooper Special (Syn. Burpees Self-pruning), a rather late blooming determinate, with Red River, an early, indeterminate vined North Dakota Agricultural Experiment Station introduction, and in 1927 introduced Viking and Fargo for trial. The former was discounted because of roughness of fruits, while the latter, although smooth, was too small. Hutchins (3), in trials at the Minnesota Agricultural Experiment Station, did not find them particularly well adapted, and regarded them less favourably than the older indeterminate, Red River. The possibilities of producing determinate varieties of merit was recognized in California, and Fargo was one of the parents used in producing the new California Agricultural Experiment Station variety Pearson, which has been described by Porter and MacGillivray (6). Further selection of the material in North Dakota resulted in the introduction of Bison in 1929. The earliness, dwarf habit, ability to set fruit under adverse conditions, general drought resistance and acceptable fruit qualities of this variety have contributed to its wide success on the Prairies.

While Bison was found to be relatively well adapted to prairie culture it was not without faults. The fruits, although of good size, were rather shallow, and tended to be rough. Like nearly all commercial varieties, it has a dark green overcolour at the stem end. While this is not objectionable in many varieties, in Bison it was often found to persist after the remainder of the fruit had turned colour. To overcome this fault a cross was made in 1930 at the North Dakota station between Bison and a tomato from the genetical material of Iowa State College. This tomato lacked the dark green overcolour, but had little else to recommend it from a commercial standpoint. In 1933, a selection, N.D. 216, was found in a mixed planting which included selections from this cross having uniform colour, and material from crosses between Bison and Bison × Ohio Red selections. Further selection resulted in Allred being made available to the public in 1937.

In trials at the Morden Experimental Station, Allred has exhibited characteristics similar to Bison both in growth and fruiting habit, and except for its uniform colour, has shown no distinct advantage. Indeed, general observations have led to the belief that, under ordinary field conditions in the Morden district, it tends to be proportionately flatter and rougher than the older variety.

In an endeavour to improve the type further, Yeager crossed Allred and Break o'Day, a 1931 United States Department of Agriculture introduction, which bears large, smooth, shapely fruit on a rather sparse foliaged, indeterminate vined plant. Two determinate varieties, Victor and Bounty, have so far resulted from the cross. Selection work on the former was

completed by Yeager at the Michigan Agricultural Experiment Station, and the variety introduced from that institution in 1940 (8). Meanwhile, Mattson (4, 5) made selections from the material at the North Dakota Station, resulting in the release of Bounty. The pedigree of Bounty and Victor is shown in Figure 1.

The fruit quality of both Bounty and Victor has been reckoned comparable to some of the better adapted indeterminate varieties. In Morden tests fruits have been smooth, firm, of good size and depth. Cells are 6 to many, often irregular, small and the walls thick, flesh fine-grained and well flavoured.

The merits of Danmark, a rather small, but smooth fruited and uniform coloured variety of determinate type, which has been introduced from Europe, have been pointed out by Babb and Kraus (1). At Morden it has been smooth and productive but on the small side for slicing purposes.

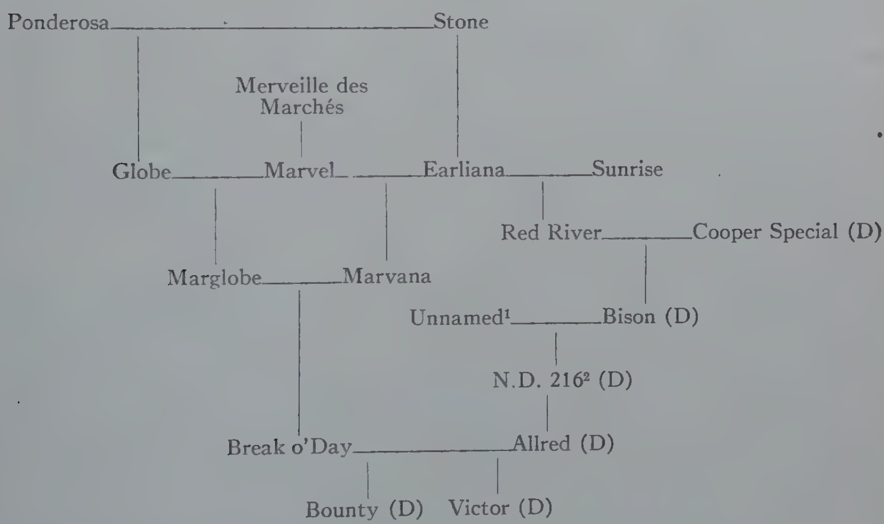

FIGURE 1. Pedigree of Bounty and Victor

METHODS

In 1940 the trial at Morden was planned as a 7 × 7 Latin Square, while in 1941 ten varieties were grown in a randomized block trial in each of 4 replicates. The varieties Break o'Day and Earliana were grown as representing indeterminate vined varieties well adapted to the district. The average date of seeding was April 15 and of setting to the field June 1. In both years the young plants were pricked off into 3 × 3 × 3 inch

[1] An unnamed, uniform colour variety from the genetical material of the Iowa State College.

[2] A selection found in 1933, in a mixed planting which included material from crosses between Bison and Bison × Ohio Red selections, and selections having "uniform colour" or absence of green overcolour at the stem end (4).

(D) Determinate vined varieties.

wooden plant bands, which were removed at transplanting. Guard rows were provided in all cases to offset border effect. Ordinary cultural practices only were given, with no additional commercial fertilizer or irrigation. Barnyard manure was, however, ploughed in each fall at the rate of 20 tons per acre. The soil in which the plots were located varies from Morden clay loam to light clay. Shelter belt protection was adequate. In 1940 plants were spaced 4 × 5 feet, with a total of 42 plants per variety and in 1941, 3 × 4 feet, with 32 plants per variety.

Pickings were made twice a week. A relatively small percentage of ripe fruit in 1940 was unmarketable due to cracking or blossom end rot, and no count of the ratio of marketable to total harvest was made. In 1941, however, more spoiling occurred, and counts were made at each harvest of the unmarketable fruit.

RESULTS

1. *Vine Spread*

Data obtained in both 1940 and 1941 demonstrate that in general, the determinate vined variety produces a smaller, more compact plant. In 1941, the average mature vine spread for 7 determinate varieties was 43 inches, and of 4 indeterminates, 56 inches (average of 4 replicates). In a Latin Square yield trial the previous season, the average spread for 5 determinates was 39 inches and for 2 indeterminates 50 inches (average of 7 replicates). Measurements of the individual varieties are given in Table 1.

TABLE 1.—Vine Spread in Yield Trials, 1940 and 1941

Variety	Vine Spread		
	1940	1941	Average
	in.	in.	in.
Determinate			
Redskin	—	32	—
Allred	36	—	—
Bison	35	40	38
Victor	40	44	42
Firesteel	42	44	43
Bounty	43	44	44
Danmark	—	44	—
Indeterminate			
Earliana	48	54	51
Dakota Red	—	52	—
Break o'Day	52	60	56
Red River	—	57	—

The difference in vine spread between the two types in observation plots was even more marked, 27 determinates averaging 30 inches, and 48 indeterminates 46 inches. Measurements made in an observation trial in 1939 showed an average spread of 32 inches for 19 determinate vined

varieties and 51 inches for 53 indeterminates. No figures in the observation plots of 1941 are available, as the indeterminate varieties were staked and pruned.

Summarizing these data for the three seasons, the difference between the mean vine spreads of the two types is found to be 15 inches. The fact that the plant of determinate growth habit is more compact than the indeterminate, indicates that it may be spaced more closely with increased yields per acre.

2. *Fruit Size*

The objection is frequently raised that those determinate vined varieties with fruits of sufficient smoothness are generally undersized. Trials in 1940 and 1941 showed the newer smooth fruited varieties, such as Bounty, Victor and Firesteel, to produce fruits averaging 4.5 ounces or over (Table 2) which is an acceptable size.

TABLE 2.—FRUIT SIZE AS INDICATED BY WEIGHT PER FRUIT OF TOMATO VARIETIES IN TRIALS AT MORDEN, 1940 and 1941

Variety	Weight per fruit		
	1940	1941	Average
	oz.	oz.	oz.
Determinate			
Bison	5.5	3.9	4.7
Bounty	4.6	4.4	4.5
Firesteel	5.9	4.9	5.4
Victor	5.1	3.9	4.5
Allred	5.8	—	—
Redskin	—	2.5	—
Danmark	—	2.1	—
Indeterminate			
Break o'Day	6.6	5.1	5.8
Earliana	5.2	3.7	4.4
Dakota Red	—	3.2	—
Red River	—	3.4	—

3. *Earliness*

The trials showed a tendency for earliness to be expressed to a greater degree by early determinate than by early indeterminate varieties (Table 3). This earliness is expressed in terms of the total yield for the first two weeks of harvest, rather than the date the first fruit ripens. For example, data from 1940 observation trials show that the average number of days from transplanting to ripening of the first fruit was 74 for both determinate and indeterminate varieties (19 of the former and 18 of the latter). This would appear to indicate no difference in season between the two types, yet the early yields showed a distinct advantage for the determinate varieties.

TABLE 3.—SEASON OF MATURITY OF TOMATO VARIETIES IN YIELD TRIALS AT MORDEN, 1940 AND 1941

Variety	Ripe fruit first two weeks of harvest		
	1940	1941	Average
	lb. per plant	lb. per plant	lb. per plant
Determinate			
Bison	2.19	1.39	1.79
Allred	1.75	—	—
Redskin	—	1.72	—
Bounty	1.20	1.52	1.36
Victor	1.12	1.05	1.08
Danmark	—	1.02	—
Firesteel	0.88	0.71	0.80
Indeterminate			
Earliana	1.82	0.82	1.31
Dakota Red	—	1.26	—
Red River	—	0.87	—
Break o'Day	0.43	0.53	0.48
Significant difference, odds of 19 : 1	0.37	0.44	

4. *Yield*

Determinate vined varieties significantly outyielded indeterminates when neither was staked nor pruned, in both 1940 and 1941 (Table 4). This table shows the marked superiority in yielding ability of determinate varieties over Break o'Day in both years. In 1941, a relatively unfavourable year, because of heavy rains late in the season, the percentage of graded or marketable fruit was greater in the determinate than in the

TABLE 4.—YIELD OF TOMATO VARIETIES, DOMINION EXPERIMENTAL STATION, MORDEN, MANITOBA

Variety	1940 (117 days)*		1941 (112 days)*				Average of total yields	
	Total		Graded		Total			
	lb. per plant	bu. per acre	lb. per plant	bu. per acre	lb. per plant	bu. per acre	lb. per plant	bu. per acre
Determinate								
Bounty	21.16	922	6.01	436	9.38	681	15.27	802
Victor	18.98	827	4.88	354	7.91	574	13.44	700
Bison	14.42	628	4.10	298	7.63	554	11.02	591
Firesteel	13.22	576	3.66	266	5.68	412	9.45	494
Allred	14.11	615	—	—	—	—	—	—
Danmark	—	—	5.94	431	7.41	538	—	—
Redskin	—	—	3.92	285	6.58	478	—	—
Indeterminate								
Earliana	19.32	842	2.28	166	6.34	460	12.83	651
Break o'Day	9.20	401	2.16	157	3.04	221	6.12	311
Dakota Red	—	—	3.46	251	6.98	507	—	—
Red River	—	—	2.46	178	6.01	436	—	—
Significant difference odds of 19 : 1	1.82	78	1.3	94	1.4	102	—	—

* Length of season, days from transplanting.

indeterminate varieties, Earliana, Dakota Red and Red River. This was accounted for by a large amount of cracking which rendered the fruits unmarketable. This evidence was also corroborated by results of trials at the North Dakota Agricultural Experiment Station (Table 5).

It appears evident from the results of trials at both stations, that the new determinate varieties are more productive than the better adapted indeterminate or older determinate varieties.

TABLE 5.—YIELD OF TOMATO VARIETIES IN RANDOMIZED BLOCK TRIALS, NORTH DAKOTA AGRICULTURAL EXPERIMENT STATION, FARGO*

Variety	1940 (105 days)†		1941 (125 days)†		Average	
	Graded	Total	Graded	Total	Graded	Total
	bu. per acre	bu. per acre	bu. per acre	bu. per acre	bu. per acre	bu. per acre
Determinate						
Bounty	553	717	389	718	471	718
Victor	491	647	315	612	403	630
Firesteel	486	672	276	517	318	594
Allred	281	590	227	697	254	644
Bison	250	596	123	494	186	545
Indeterminate						
Break o'Day	398	459	167	238	282	348
Earliana	321	638	64	403	192	520
Significant difference odds of 19 : 1	44	58	45	70		

* These trials were made under the direction of Harold Mattson, Horticulturist. Appreciation is expressed for permission to use these data and for the co-operation of the North Dakota Station.

† Length of season—days from transplanting to frost.

DISCUSSION

The performance of the newer determinate varieties has been very satisfactory as to season, total yield and culinary quality. The variety Bounty in particular has shown much promise and warrants extensive trial. When compared to Earliana, which is considered one of the best indeterminates for prairie conditions, it was found to be earlier in season in 1941, later in 1940, and to average about the same. In total yield, however, Bounty was more productive by a significant margin in both years. In addition, the graded yield of this variety in 1941 was more markedly in excess of Earliana than the total yields, due mainly to the severe cracking habit of the latter. The dwarf habit of the determinates eliminates the necessity of staking, and where labour is at a premium the grower would be well advised to give them a trial. It is believed that their use will eliminate many of the failures experienced by amateurs who heretofore have grown indeterminates unpruned and unstaked.

The results of these trials lend confidence to the belief that the improved varieties of determinate type will find widespread use and increasing importance on the prairies.

SUMMARY

1. The vine spread of determinate vined tomato varieties was significantly less than that of indeterminates.

2. The newer determinate varieties such as Bounty, Victor and Firesteel produced fruits of acceptable size.

3. Earliness (total yield for the first two weeks of harvest) was expressed, for the most part, to a greater degree by early determinates than by early indeterminates.

4. Determinate vined varieties significantly outyielded indeterminates when neither was pruned and staked.

ACKNOWLEDGMENT

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SOIL COLLOIDS[1]

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That fraction of the soil which is designated by the term "colloids" is recognized as the seat of many of the reactions which take place within the soil body. Some knowledge of that fraction is therefore of great importance to the student of soil science. In this paper, there is presented a review of some of the theories on the formation, structure and behaviour of the colloidal complex.

In considering colloids, it is necessary to remember that one is dealing with a state, rather than a form, of matter, and also one is dealing with a system of at least two components or phases, a discontinuous or disperse phase, and a continuous phase or dispersion medium. In general terms, a colloidal system results whenever one material is divided into a second with a degree of subdivision either *(a)* coarser than molecular or *(b)* where the micelles or particles exceed 1 to 1.5 mμ in diameter. The arbitrary boundaries usually accepted for materials in the colloidal state is a minimum of 1 mμ (0.001 μ) and a maximum of 0.1 μ, though there is a tendency with some to increase the upper limit to 0.5 μ or even to 1 μ.

The earliest work on colloids was published by Thomas Graham about 1861 64. He recognized two groups of substances which he called colloids and crystalloids. Colloids formed colloidal solutions, but crystalloids formed true solutions. Subsequent work, however, has shown that almost any substance can be obtained as a colloid by proper preparation, and this has served to emphasize the fact that colloidal materials represent a state rather than a form of matter.

Particles of colloidal dimensions have very large surfaces in proportion to their mass; consequently, they play a very important part in reactions where surface effects are important. Colloidal solutions exhibit special behaviour toward electrolytes. At certain concentrations of electrolytes, the dispersed particles lose their stability and precipitate out of solution or flocculate. This behaviour is somehow related to the electric charge which these particles carry. A colloidal particle in solution is believed to consist of a nucleus surrounded by ions which are more or less firmly fixed to it and give the electric charge to the particle. In water, these particles are usually negatively charged. The charged particle is further surrounded by a diffuse layer of ions of the opposite sign which are attracted by the charged particle, and some of these carry molecules of water of hydration with them. The whole particle with its surrounding ions is called a micelle.

One can consider soil in a broad sense as being made up of four components, mineral material, organic matter, water and air. A large part of the mineral material consists of fairly large particles and makes up what might be called the framework of the soil body. An important part of the

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mineral matter, however, is of colloidal dimensions and hence is important in the reactions that take place in the soil. In making a mechanical analysis of soil according to the International method, the material which passes a 2 mm. screen is used. After destroying the organic matter by oxidation, the remaining mineral matter is divided into the following fractions: coarse sand, 2.0 – 0.2 mm.; fine sand, 0.2 – 0.02 mm.; silt, 0.02 – 0.002 mm.; clay, less than 0.002 mm. The clay fraction is determined by making use of the settling velocity of small particles according to Stokes' law. It is the clay fraction that makes up the colloidal mineral matter of the soil. Most of the soil organic matter is considered to exist in the colloidal state. Because of their reactivity, the colloidal materials of the soil, which make up the so-called "colloidal complex", are of outstanding importance in the reactions and changes that take place.

One of the important properties of the colloidal complex is the holding in readily available form of a number of the important elements in plant nutrition, viz., the bases Ca, Mg, K and Na. The phenomenon of base exchange in soils was first observed about the middle of the last century and much work was then carried out by Thompson and Way in England. Thompson first noticed the adsorption of ammonia by soil and Way followed this up by the observation that an equivalent amount of calcium was displaced by this ammonia. This opened up a big field of research in an attempt to discover the source of these reactions. It was originally ascribed to the clay fraction of the soil, but, since colloidal organic matter also has the power of adsorbing bases, the colloidal complex is now considered to be the source of the base exchange reactions.

The nature of the predominating cation in the exchange complex has considerable influence on the physical condition of the soil. Calcium causes a flocculation of the colloids and results in good physical condition. Sodium, on the other hand, brings about a dispersion of the colloids and the soil becomes sticky and difficult to work. The phenomenon of base exchange is important in the retention in the soil of added fertilizer salts. An element such as potassium, which is added either as the chloride or sulphate, might be expected to be leached out as the result of a heavy rain, but when it enters the exchange complex, it is retained in a form that is readily available to plants.

It was stated above that the base exchange reactions were originally ascribed to the clay fraction of the soil and it was believed that certain complex alumino-silicates were responsible. For a long time, a great deal of emphasis was placed on the importance of the silica-alumina ratio of the clay fraction. The presence of iron oxides was believed to be adventitious, but certain workers later came to the conclusion that iron compounds formed essential ingredients of the clay complexes. Consequently the silica-sesquioxide ratio was thought to be important. References to both ratios are to be found. Russell (12) of Rothamsted has stated that the essential part of the clay fraction appeared to be the alumino-silicic acid and many properties of the clay showed a regular gradation with variations in the molecular proportions of SiO_2 and Al_2O_3. Typical clay properties of stickiness, shrinkage and colloidal properties in general did not appear when this ratio was 2 or less, but they became more and more intense as

the ratio rose to 5 or 6. Capacity for base exchange and the power of absorbing water and ammonia all increased as the ratio increased.

The silica-sesquioxide ratio in the clay is in part determined by its origin and in part by the climatic conditions to which it has been subjected. Analyses have shown that, in the humid temperate regions, this ratio is higher than in the humid warm regions. A general relationship was thought to exist between the silica-sesquioxide ratio of the colloids and base exchange capacity. Colloids with low ratios were found to possess lower exchange capacities than those with higher ratios. More recently, however, some workers have produced evidence to show that this relationship does not hold generally.

In discussing the clay complex, Robinson (10) recognized three so-called fractions which he described as follows: (1) the clay fraction, which in the mechanical analysis of a soil is defined in terms of particle size or settling velocity; (2) the colloidal fraction or complex, which is the reactive mineral constituent of the soil; and (3) the weathering complex, which consists of materials of secondary origin which have resulted from the chemical weathering of silicate minerals. He concluded that, although these fractions were not completely identical, for most soils there would be no great error in assuming that they were identical. That is, one may conclude that the inorganic colloidal material of a soil is formed by the chemical weathering of original rock minerals. In discussing the results of weathering, Brown and Byers (1) of the U.S.D.A. in Washington, have considered some theoretical possibilities. They have assumed, in the first place, that the chief chemical reaction that takes place in weathering is hydrolysis; that the degree of hydrolysis is governed largely by rainfall, temperature and vegetation, with the character of the primary material only a minor factor; that the hydrolysis of the minerals takes place in definite steps, giving rise to definite compounds; and that since the process of soil formation is continuous, no single soil can be expected to contain one colloid component only, but in each soil, one component may be expected to dominate.

Studies of the colloids of the great soil groups by Byers and others have revealed that there are three general types: (1) colloids essentially alumino-silicates of high SiO_2/Al_2O_3 ratio and corresponding in general character to the colloid of montmorillonite; (2) colloids with a SiO_2/Al_2O_3 ratio of approximately 2, essentially of the general type of halloysite; (3) those in which the dominant colloid consists essentially of a mixture of the hydroxide of alumina, more or less dehydrated, and of iron oxide, more or less hydrated. Now, on the assumption that inorganic soil colloids might be regarded as essentially products of hydrolysis of the feldspars, because of the relatively enormous quantities of feldspars in igneous rocks (approximately 60%), the following hypothetical reactions were suggested (Figure 1):

On the basis of these assumptions, the following derivatives of the feldspars are obtained, showing decreasing silica-alumina ratios:

$3H_2O . Al_2O_3 . 6SiO_2$	Montmorillonitic acid
$3H_2O . Al_2O_3 . 4SiO_2$	Pyrophyllic acid
$3H_2O . Al_2O_3 . 2SiO_2$	Halloysitic acid
$3H_2O . Al_2O_3$	Aluminium hydroxide

Figure 1

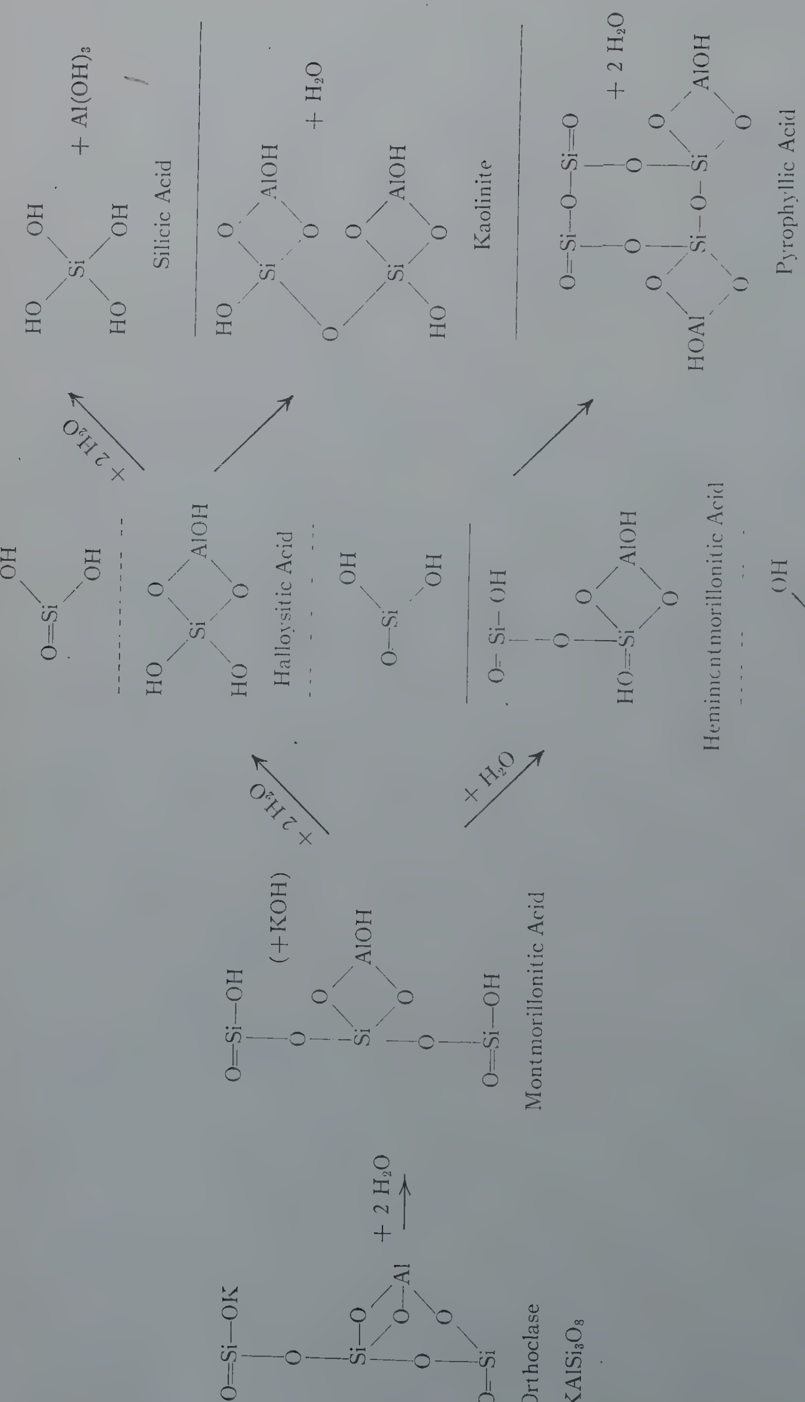
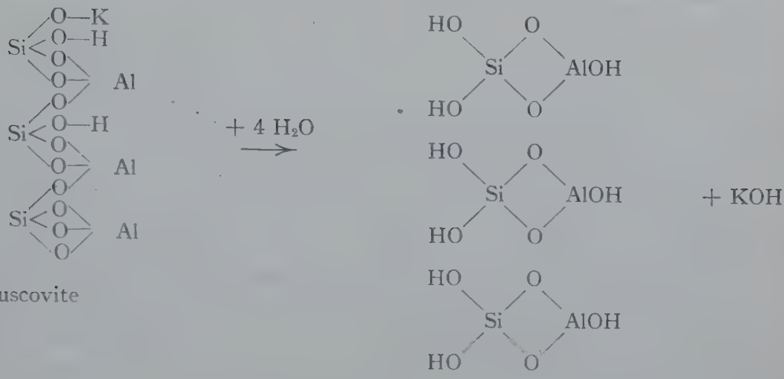

Orthoclase
$KAlSi_3O_8$
$+ 2\ H_2O$
(+KOH)
Montmorillonitic Acid
$\times 2\ H_2O$
$\times H_2O$
Halloysitic Acid
Hemimontmorillonitic Acid
$\times 2\ H_2O$
$+ Al(OH)_3$
Silicic Acid
$+ H_2O$
Kaolinite
$+ 2\ H_2O$
Pyrophyllic Acid

FIGURE 1—*Concluded*



Muscovite

Halloysitic Acid

It has already been mentioned in the general discussion on colloids that there is no fundamental difference between colloids and crystalloids, but that practically all substances can, under proper conditions, be obtained in the colloidal state. Until fairly recently, soil scientists believed that the colloids were non-crystalline in nature, although in 1924 Robinson and Holmes (11) suggested that a large part of the SiO_2, Al_2O_3, Fe_2O_3 and H_2O of soil colloids might be present in the form of some definite mineral and predicted that a further development of X-ray methods might indicate that they were composed of crystals. It was not until 1930, however, that the first evidence of the crystalline nature of soil colloids was presented by Hendricks and Fry (5) of the U.S.D.A. and their work was soon substantiated by results published by Kelley, Dore and Brown (7) of California. Since then, a great deal of work has been done along this line and, at the present time, the crystalline nature of the inorganic soil colloids is generally accepted. There are five lines of evidence which have been used to substantiate this theory: (1) X-ray crystal analysis; (2) optical properties; (3) results obtained by grinding; (4) dehydration studies; (5) influence of dehydration on the X-ray spectrograph.

The first mentioned is perhaps the most important and was the main one used by the workers mentioned above. It is based on the following principles: In crystalline substances, the constituent atoms are located at regularly spaced distances in the various directions, thus forming a regular three-dimensional space lattice. The regularly spaced atoms fall into planes and these planes are also regularly spaced. Because the interplanar spacings are of about the same order of magnitude as the wavelengths of X-rays, the planes of atoms in a crystal are capable of acting as the diffraction grating for X-rays in much the same way that the closely ruled lines on a glass plate diffract the waves of visible light. In practice, the powdered crystalline material is examined in an X-ray diffraction apparatus and a series of lines is recorded on a photographic film and these give a diffraction pattern characteristic of the substance producing it. The production of a pattern is direct evidence that the substance is crystalline, since a non-crystalline material would produce a general fogging effect on the plate.

The diffraction patterns produced by a number of soil colloids showed definite evidence of crystallinity. Furthermore, comparison of these patterns with those obtained from known clay minerals showed a strong resemblance and indicated that the constituents of the soil colloids were closely related to those materials known to mineralogists as the clay minerals. Some of the colloids approached the structure of the kaolinitic minerals of which halloysite is a member, and others resembled the chief minerals of the bentonite clays, of which beidellite and montmorillonite are important members.

The optical property that is made use of in determining the crystallinity of soil colloids is the refractive index. Most of the colloids examined were birefringent, i.e., showed double refraction. Results showed that the colloids gave refractive indices similar to those of beidellite, halloysite and nontronite.

By grinding soil colloids, a profound increase in base exchange capacity was obtained and the same was true of a considerable number of other minerals. With those colloids that resembled halloysite, a large increase in the amount of exchangeable hydrogen was obtained. On the other hand, with colloids that resembled beidellite, no increase in hydrogen ion concentration was obtained, but the amount of exchangeable magnesium and potassium was increased, sometimes very markedly so. A further observation was that the amounts of exchangeable calcium and sodium were not increased. This was taken to mean that magnesium and potassium formed part of the crystal structure of these minerals, whereas calcium and sodium were merely adsorbed on the surface.

Studies of dehydration of colloids further supported the theory that they were crystalline in nature. Colloid materials were pretreated under standard conditions of humidity, then heated to constant weight at definite temperatures up to about 750° C. Dehydration curves were then plotted from the results. The evidence indicated very strongly that these colloids contained hydroxyl groups in their crystal lattice. As in previous cases, some curves resembled those of halloysite while others resembled those of beidellite. Dehydration curves of mica were distinctly different from those of soil colloids and clay minerals.

Further evidence was obtained by studying the crystal structure of these colloids by means of X-rays, both before and after dehydration. When this was done, it was seen that dehydration caused a shift in one of the lines of the X-ray spectrograph. The simplest explanation offered for this was that the crystal lattices occurred in sheets or packages and these packages were held together so loosely as to permit the entry and exit of water molecules into and from between them.

Marshall (8) has summarized the theories of crystal structure of the soil colloids from the point of view of the clay minerals. According to these theories, the layer lattices are built up of layer units of three common types: (1) a silica layer consisting of a sheet of linked silicon and oxygen atoms, each silicon being attached to four oxygen atoms in a tetrahedral arrangement; (2) a layer in which an aluminum atom lies at the centre of an octahedral arrangement of six oxygen atoms; (3) a layer in which a magnesium atom lies at the centre of an octahedral arrangement of six oxygen atoms

(with more Mg atoms than there are Al atoms in the previous type of layer). The lattice structures are made by these layers being superimposed on one another, the layers being held together by unsatisfied valences of the elements of the different layers. Two types of structure are possible, a symmetrical one of three layers such as Si—Al—Si or Si—Mg—Si, and an unsymmetrical one of two layers such as Si—Al. Some adsorption of exchangeable ions on the surface of these structures may take place, due to the presence of unsatisfied valences. Different clay minerals may be formed by substitution of one element for another in the lattice structures. There are three main types of substitution, Mg for Al, Al for Si and Fe for Al. In this substitution, more unsatisfied valences may occur inside the crystal structure, with the result that some exchangeable ions may be found between the lattice layers. Marshall divided the bases usually classed as exchangeable into two categories, those which may be fixed in the lattice structure (Mg and K) and those which are almost all exchangeable (Na and Ca). He stated that the bulk of the exchangeable ions are to be found between the charged layers and only a small proportion of the total exchangeable cations form the outer portion of the electrical double layer surrounding the particle.

With regard to the silica-sesquioxide ratio, to which great importance has in the past been attached, Marshall concluded that it does not even roughly indicate the type of clay mineral that may be present, or show any relationship to the base exchange capacity, so that it is largely meaningless in characterizing clays. This is because of the possibility of replacing one element by another in the crystal lattice. Thus, for example, it is possible that, if certain substitutions take place simultaneously, the negative charge on the particle may increase (thus increasing the base exchange capacity), while the silica-sesquioxide ratio may remain almost constant.

The position of phosphorus was discussed and it was shown that phosphorus may also occur in the crystal lattice structure of the clay minerals. Whether or not phosphorus added to a soil as a fertilizer actually assumes such a position has not as yet been shown.

Summing up, therefore, the present theories on the structure of the inorganic soil colloids, it may be stated that their crystalline nature is generally accepted and that they are related to the clay minerals. Two main groups may be distinguished, with perhaps a smaller third group (4). The first of these is called the kaolin group, with an ideal composition of $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$. Four individual members of this group are recognized, kaolinite, halloysite, dickite and nacrite. Only the first two have actually been identified in soil colloids. Their lattice unit consists of one Al layer and one Si layer. Their base exchange capacity is small.

The second group is known as the montmorillonite group, and is given the ideal formula $Al_2O_3 \cdot 4SiO_2 \cdot H_2O + xH_2O$. Minerals included in this group are montmorillonite, beidellite and nontronite. The structure consists of one Al layer and two Si layers. The lattice units are separated by spaces of variable width containing water and exchangeable cations. The base exchange capacities of minerals of this group are greater than those of the other clay minerals.

A third group is referred to by Hendricks (4, 5) as "Ordovician bentonites" or "hydrous micas". The minerals of this group are believed to be related to the micas, but not identical with them. Early workers thought that this might not be a separate group, since a mixture of montmorillonite and quartz had similar characteristics. Other accessory minerals that may be present are those containing iron oxide, aluminum hydroxide, titanium and phosphorus. Calcite may also occur in small amounts in certain soils.

On turning to a study of the organic soil colloids, it is found that not a great deal is known about them as such. The great difficulty in the way is the problem of obtaining them in the pure state. With inorganic colloids, it is possible to separate the colloidal material as a whole, then destroy the organic part by oxidation with, e.g., hydrogen peroxide. In this way, the inorganic fraction is obtained in a more or less pure state. No such method can be followed to rid the colloid of its inorganic fraction and retain the organic fraction for further investigation.

It is believed, however, that by far the largest part (up to 80% or more) of the total organic matter of the soil is in the colloidal state. The method that has been most commonly used to study the organic matter is to extract the soil with an alkali (NaOH or NH_4OH) and precipitate the so-called humic acids by acidifying the alkali extract. However, it is generally considered that, even assuming this represents the whole of the organic colloid, it is considerably altered physically and results obtained with it cannot be immediately applied to the soil. A second method that has been used is to study a number of soils containing varying amounts of organic and other colloids and to try to find correlations between results obtained and the amount of organic matter as measured by the carbon content. There is also a third indirect method. Since the organic matter of the soil is formed by the decomposition of organic residues of plant and animal origin, studies of the decomposition products of such materials outside the soil might be expected to give some indication of the nature of these products within the soil.

Soil organic colloids have a high capacity for absorbing water, show great changes of volume on wetting and drying, and are less sensitive to electrolytes. Plasticity is not a distinctive characteristic of this type and they show cohesion to a much less degree than do the inorganic colloids. It is believed that each particle is surrounded by an electrical double layer and it is known that their base exchange capacity is high, several times that of the inorganic colloids. The exchange capacity of colloidal clay has been given as varying from 16 to 110 milliequivalents per 100 grams, while the range for organic colloids is thought to be from 250 to 450 milliequivalents per 100 grams. Just what the composition of the material is that gives the property of adsorption and base exchange to the organic fraction is not known. It is thought that lignin plays an important part, since it does not readily decompose, but the base exchange capacity of lignin alone is rather low. Waksman (14) has suggested that a ligno-protein complex is formed. When such a complex was formed synthetically, it had a higher base exchange capacity then either constituent alone, and it was similar in nature to humus.

It has long been thought that the organic matter of a soil forms a coating over some of the inorganic particles and acts as a protective colloid.

In soil, where the different constituents are so completely mixed together, it is to be expected that the organic and inorganic colloids would form complexes which behave almost as single units. The difficulty of separating the organic from the inorganic colloids has already been mentioned.

Schloesing in 1876 first suggested that clay combined with soil humus to give colloidal compounds, the extent of combination depending upon the soil reaction and the content of exchangeable bases. By treatment with alkalis, Waksman isolated from a number of soils an organic-inorganic complex of varying chemical composition. It has also been observed that, when organic colloids are mixed with inorganic colloids, there is a reduction in cation exchange capacity from the sum of the capacities of the two components. Recently, some work has been done at Illinois (2, 3) in an attempt to show the nature of the union between organic and inorganic materials. Montmorillonitic clay was selected as representing one of the common constituents of soil inorganic colloids and protein was chosen as being one of the common organic substances that might be expected to take part in such reactions in the natural state. These materials were mixed at high pH values where both behave as negative colloids and, consequently, no reaction between the two takes place. The pH was then lowered, when the protein became positive and a precipitate was formed and settled out. The resulting material was examined by the X-ray diffraction method, when a shift in one of the lines of the montmorillonite plate was observed. This was taken to mean that the protein molecules had united chemically with the unsatisfied valences of the clay crystal, not only on the surface but also within the variable lattice spacing. The base exchange capacity of the clay was also reduced by this treatment with protein and it was assumed that this was due partly to the combination of some of the valences of the clay with the protein, and partly to steric hindrance, the presence of large protein molecules preventing ready access of other cations.

A discussion on soil colloids would not be complete without some reference to the work of Sante Mattson, Over a period of about 12 years, this worker has published a series of papers on the "Laws of Soil Colloidal Behavior" which now numbers twenty-three (9). He has approached the study of the soil colloids from a purely theoretical point of view. Early experiments were carried out on the formation of precipitates of iron and aluminum hydroxide gels from the chlorides and sulphates of these elements. Standard solutions of NaOH and $AlCl_3$ or $Al_2(SO_4)_3$ were mixed, the amount of one being kept constant and that of the other varied. The degree of flocculation, both immediately after mixing and after standing overnight, was noted and the pH value obtained. In addition, the sign of the charge on the flocculated particles was determined by cataphoresis ultramicroscopically, and it was observed that, in a series, at a certain pH value, the sign of the charge changed from positive to negative. The precipitate which was cataphoretically neutral was termed the "iso-electric precipitate". Examples of the results obtained are given in Tables 1 and 2:

TABLE 1.*—RESULTS OBTAINED ON MIXING SOLUTIONS OF $AlCl_3$ AND NaOH

5.0 millimols $AlCl_3$ per litre
20.0 millimols NaOH per litre

$AlCl_3$ solution	NaOH solution	Flocculation		Cataphoresis	pH
		After mixing	Overnight		
cc.	cc.				
20	14.5	Clear	0	—	—
20	15.0	Instant	xxxx	+1.38	—
20	15.5	Instant	xxxx	+0.61	7.7
20	16.0	Instant	xxxx	±0	8.1
20	16.5	Instant	xxxx	−0.47	8.4
20	17.0	Instant	xxxx	−0.67	—
20	17.5	Rapid	xxxx	−1.01	—
20	18.5	Clear	x	—	—

* Mattson, Table 29, Soil Sci. *30*, 461. 1930.

TABLE 2.*—RESULTS OBTAINED ON MIXING SOLUTIONS OF $FeCl_3$ AND NaOH

5.0 millimols $FeCl_3$ per litre
20.0 millimols NaOH per litre

$FeCl_3$ solution	NaOH solution	Flocculation		Cataphoresis	pH
		After mixing	Overnight		
cc.	cc.				
20	14.5	Clear	0	—	—
20	14.75	Opal	xxxx	+2.53	6.2
20	14.88	Instant	xxxx	+1.29	6.5
20	15.0	Instant	xxxx	+1.04	6.75
20	15.12	Instant	xxxx	+0.93	6.9
20	15.25	Instant	xxxx	±0	7.1
20	15.38	Instant	xxxx	−0.48	7.2
20	15.5	Instant	xxxx	−1.08	7.55
20	15.75	Clear	xxxx	−3.20	8.2

* Mattson, Table 30, Soil Sci. *30*, 461. 1930.

An analysis of these precipitates showed that they were not pure "hydroxides" but retained some of the ions from the solutions. Comparison of the precipitates from the chloride and the sulphate showed that more of the sulphate than the chloride was retained, and that the isoelectric point of the sulphated complex was lower. The explanation given is that the sulphate ion is much less dissociated by the complex than is the chloride ion. The isoelectric point has been described as that point at which the complex dissociates an equal number of anions and cations. At this point, swelling, viscosity, osmotic pressure, etc. are at a minimum and purification, i.e. removal of diffusible ions, is most readily accomplished.

The colloidal complex of the soil is considered by Mattson to result from mutual precipitation, at or near isoelectric conditions, between electropositive or basic sols on the one hand, and electronegative or acidic sols

on the other. The important basic constituents are iron and aluminum, while silicic acid, humic acid and phosphoric acid constitute the main acidic materials. Mattson extended his laboratory study to include the precipitates formed by the interaction of solutions of these various substances. Proteins are amphoteric and may react acidic or basic, depending on the pH of the medium. Thus it was possible to prepare iron and aluminum "proteinates" as well as protein "silicates", "humates" and "phosphates". It was found that the constitution of the isoelectric precipitates so formed, as well as the isoelectric pH values varied with the concentration of the solutions used in their formation, and also with the reaction of these solutions. Some of the results obtained are illustrated by the following:

EFFECT OF CONCENTRATION OF SOLUTIONS ON THE COMPOSITION AND pH OF THE ISOELECTRIC PRECIPITATE

$$\left\{ \begin{array}{l} 4.96 \text{ millimols } AlCl_3 \\ 10.156 \text{ millimols } Na_2HPO_4 \end{array} \right\}$$

	In 500 cc.	In 2500 cc.	In 5000 cc.
Isoelectric pH	4.85	4.9	5.2
Composition	$Al_2O_3 . (P_2O_5)_{0.897}$	$Al_2O_3 . (P_2O_5)_{0.857}$	$Al_2O_3 . (P_2O_5)_{0.790}$

EFFECT OF REACTION OF SOLUTIONS ON THE COMPOSITION AND pH OF THE ISOELECTRIC PRECIPITATE

5.0 millimols $AlCl_3$ in 1000 cc. 7.5 millimols Na_2SiO_3 in 1000 cc.	5.0 millimols $AlCl_3$ in 1000 cc. 7.5 millimols Na_2SiO_3, 15 millimols NaOH } in 1000 cc.
Isoelectric pH — 6.25	Isoelectric pH — 6.6
Composition — $Al_2O_3 . (SiO_2)_{1.63}$	Composition — $Al_2O_3 . (SiO_2)_{1.09}$

The terms acidoid, basoid and ampholytoid have been introduced by Mattson. These refer to the colloidal, insoluble fraction of electrolytes which dissociate into hydrogen and hydroxyl ions and non-diffusible ion complexes, as distinguished from acids, bases and ampholytes which are molecularly dispersed and dissociate into diffusible anions and cations. He regards the colloidal complex as being formed by the partial combination of acidoids and basoids, and this will react both acidic and basic. The uncombined acid valences constitute the seat of cation adsorption and exchange, whereas the free basoid fraction is responsible for the adsorption of anions. The exchange capacity of soil colloids, therefore, depends primarily on the acidoid : basoid ratio. A high ratio means a high cation and low anion exchange capacity, and a low ratio means a low cation and high anion exchange capacity.

In general, according to this theory, all the properties of the soil colloidal complex depend on its acidoid : basoid ratio. While for most mineral colloids this can be expressed approximately by the silica : sesquioxide ratio, it does not hold if there is any appreciable amount of organic matter present, since humic acid is relatively much stronger than the silicic acid fraction. Quantitative analysis alone does not give sufficient information; further measurements are needed and some have been suggested by Mattson. The natural colloid as obtained from a soil contains a

certain amount of dissociated anions and cations. If this colloid is submitted to electrodialysis, these will be replaced by hydrogen and hydroxyl ions and the colloid will then be in an unsaturated or completely desaturated condition. The pH of this material has been termed the ultimate pH and can be taken as an index of the acidoid strength. When the electrodialyzed colloid is mixed with the solution of a neutral salt, e.g. Na_2SO_4, the pH of the mixture usually is lower than that of the salt solution alone. An "exchange acidity" is developed. If the salt solution is gradually made more acid, a point will be reached where addition of the electrodialyzed colloid brings about no change in the pH. This has been termed the point of exchange neutrality. If the salt solution is made still more acid, then, when the electrodialyzed colloid is added, the resulting pH of the mixture will be higher than that of the salt solution. Here, an "exchange alkalinity" is developed. This behaviour is peculiar to all amphoteric colloids. The determination of the pH of exchange neutrality gives a measure of the relative strength between acidoid and basoid. More recently, the point of exchange neutrality, as here defined, has been termed the equi-ionic point.

According to Mattson, the soil colloidal complex must be regarded as dynamic, never the same under any two sets of conditions. This is illustrated by the variations in the composition of the isoelectric precipitates formed by the interaction of solutions of different concentrations and different reactions, examples of which have been given. The constitution of the complex will tend to undergo modification in the direction of maximum stability under prevailing conditions. This plays an important part in soil formation. Hydrolysis is regarded as one of the important reactions in the weathering of rocks and in the process of soil development. It is probable that the two extreme types of soil formation, viz., podsolization and laterization, represent nothing but an acid hydrolysis in the first case and a basic hydrolysis in the second. In a soil, soluble and even colloidally dispersed materials follow the movement of water. This means a more or less continuous removal of soluble and highly dispersible products of a reaction from the insoluble and less dispersible products. Colloidal materials are more dispersible in a charged than in the isoelectric condition. An amphoteric colloid is least ionized at the isoelectric point and possesses a tendency to alter its composition in such a way that its isoelectric point coincides with the prevailing pH.

In the process of weathering and soil formation, therefore, the tendency will always be toward the formation of compounds possessing maximum stability under existing conditions. Changes in the reaction and in the concentration of soluble materials brought about by leaching, etc., will necessitate adjustments because of the development of different environments. It must not be assumed, however, that products of hydrolysis necessarily unite to form an isoelectric complex at the very outset. While the isoelectric complex possesses maximum stability, it is not the only stable compound, and comparative high stability may extend over a wide range on either side of the isoelectric point. There must, however, be a gradual if slow trend toward an isoelectric composition.

Mattson has stated that "the interaction of the various forms of organic matter with the mineral complex is an important problem which deserves a thorough investigation." Some work along this line has been done by the

Russian worker Tyulin (13) who has studied what he terms the "organo-mineral gels" of the soil. He classified the soil colloids into two groups, the electronegative and the isoelectric colloids. The former are normally flocculated by the divalent bases calcium and magnesium. When these bases are replaced by sodium ions at pH 7, the electronegative colloids can be dispersed in water and removed. The isoelectric colloids, however, are not dispersed at pH 7, but when the pH is increased, as, e.g., by weak alkali, they become increasingly electronegative and can be dispersed and separated. The different fractions thus obtained can be further treated to remove the loosely-bound organic matter and also part of that which is more firmly held. This method of attack seems to offer good possibilities for the study of a number of soil problems.

A recent publication (6) discussed the subject of "clay-humus complexes and soil fertility", and reviewed the results of Tyulin's work together with that of certain other investigators who have studied more particularly the organic fraction. Mention was made of the work of Meyer (Forschungsdienst 11, 344–355, 1941) who, it was stated, concluded "that the formation of natural clay-humus complexes takes place 'in statu nascendi', i.e., they are formed at the moment when the primary rock minerals are being converted via permutite-like substances into montmorillonitic or micaceous colloids, by interaction with true humic acids formed simultaneously within this mineral medium. They are not formed by combination of already existing clay and humic substances."

In the foregoing, an attempt has been made to point out the importance of the colloidal material of the soil and to present some of the results obtained and theories propounded in this very complicated study. There appear to be two main theories. One attacks the problem on the assumption of the crystalline nature of the inorganic colloids and seeks to explain the various reactions on that basis. Such a theory does not take into consideration the important part played by the organic matter, since, in all studies of this nature, the organic matter is first destroyed. The other theory considers that the colloids are formed by the isoelectric precipitation of materials of acidoid and basoid nature, the basic materials considered being the sesquioxides. On the surface, it would appear that these theories are not altogether in harmony. Perhaps some of the more recent work briefly referred to above, is a step in the direction of fitting all the experi mental facts so far developed into one picture.

SUMMARY

The importance of soil colloids is pointed out and there is presented a review of some of the theories on the formation, structure and behaviour of the soil colloidal complex. On the assumption that the inorganic colloidal material of a soil is formed by the chemical weathering of original rock minerals, chiefly by means of hydrolysis, Brown and Byers have outlined some hypothetical reactions to explain the formation of different clay minerals such as montmorillonite, halloysite, etc., which are found in the clay fractions of soils, and these reactions are presented. The crystalline nature of the inorganic soil colloids is briefly discussed, together with an outline of the evidence on which the theories regarding their structure are

based. Reference is made to the work of Mattson who concludes that the soil colloids are formed by mutual precipitation, at or near isoelectric conditions, between electropositive or basic sols on the one hand, and electronegative or acidic sols on the other. The properties of soil colloids are believed to depend to a large extent on the relative proportion of these constituents in the colloid. Mention is also made of Tyulin's study of the organo-mineral gels, in which he outlines a method of separating soil colloids into electronegative colloids and isoelectric colloids, and of further fractionating each of these groups. It is believed that this method may prove useful in the study of a number of soil problems.

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THE VALUE OF DOUBLE CROSS HYBRIDS INVOLVING INBREDS OF SIMILAR AND DIVERSE GENETIC ORIGIN[1]

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INTRODUCTION

The growing of corn occupies an important place in agriculture in southern Ontario, where approximately 525,000 acres of this crop are now grown annually. For the province, the average yield per acre of corn for grain was 46 bushels; for ensilage, 10 tons, in 1941. Damage by corn borer in 1926-27 resulted in marked reduction in corn acreage for several years, but since 1930 a gradual increase has been noted.

While central and eastern districts of Ontario are concerned with the growing of corn primarily for ensilage, the southwestern part of the province is the important grain producing area, almost 200,000 acres being devoted to this purpose. The counties of Essex and Kent, which constitute 6% of the agricultural land of Ontario, in 1940 alone produced 64.5% of grain corn of the province.

The development of hybrid corn furnishes an outstanding example of the important contribution that scientific research has made to practical agriculture. Prior to 1938, the growing of hybrid corn in Ontario had been confined to a few demonstration plots, but in that year about 200 acres were grown commercially. The merits and superior qualities of hybrid corn were quickly realized by many growers in Ontario, with the result that during the past three years increase in acreage has been phenomenal. The acreage planted to hybrid corn was 25% in 1939, 50% in 1940, and 75% in 1941.

During the first three years (i.e., 1938-40) most of the hybrid seed was imported from the United States. In 1938 the total hybrid seed production in Ontario amounted to only $42\frac{1}{2}$ bushels. In 1942, however, sufficient locally produced seed will be available to plant 75% of the 525,000 acres devoted to the growing of corn in Ontario.

In Ontario investigational work in corn breeding has been carried on principally by the Experimental Farms Branch of the Dominion Department of Agriculture at the Central Experimental Farm, Ottawa, and at Harrow, situated in Essex County in southwestern Ontario. Corn breeding was inaugurated at Harrow in 1923, when a start was made in the inbreeding of selected lines. In the same year, the European corn borer made its appearance in southwestern Ontario. By 1926 the infestation had become so severe that great difficulty was experienced in maintaining inbred lines that were being developed. As a result the latter were sent to Ottawa, the corn borer not yet having appeared in the eastern part of the province. Although corn breeding was resumed at Harrow in 1930, the importance of the work really dates from 1935, since it was from that year that rapid expansion has taken place.

[1] A thesis presented to the Faculty of the Graduate School of the University of Minnesota in partial fulfilment of the requirements for the degree of Master of Science.
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An extensive plant breeding program requires a definite system and useful criteria by which a basis of selection and testing can be set up. The corn breeder is fortunate in this respect that several sound principles have been established for this purpose. All of these are employed in the present corn breeding program at Harrow.

In developing high yielding crosses the ability of one inbred to combine well in crosses with other inbreds is of the utmost importance. It is impossible to classify accurately the combining ability of inbreds on the basis of their performance as inbreds. The top crossing method has been generally adopted as a means of testing the combining ability of inbreds, and as a basis of eliminating the less desirable inbred lines.

The results of numerous studies lead to the conclusion that hybrid vigour is the greatest in single crosses between two inbred lines which bring together different groups of favourable growth factors. Crosses of inbreds that have genetic diversity should therefore on the average give a higher degree of hybrid vigour than those arising from similar origin.

It is the purpose of the present study to investigate the relationship of yielding ability of single crosses and predicted double crosses to that of the top crosses of the inbreds contained in them. The effect of genetic diversity of the inbreds on the resulting yield of single crosses and on the predicted yield of double crosses is also studied.

REVIEW OF LITERATURE

In producing high yielding single crosses and double crosses, Nilsson-Leissner (15) and Jorgenson and Brewbaker (13) showed that it was advisable to use the most vigorous inbred lines. High yielding crosses do not appear as chance combinations, but occur quite definitely among crosses involving outstanding parents. This was shown in Jenkins' (7) correlation studies, in which he found that different inbred lines gave marked differences in prepotency for practically all characters. Davis (3) at Porto Rico used the top cross as a means of selecting the better combining lines. Although the inbred lines used had only been selfed for two generations, it was thought that the best lines for additional selfing could be determined on the basis of the top cross performance.

The preliminary testing of new inbred lines for combining ability by means of top crosses was found to be quite adequate by Jenkins and Brunson (10). These investigators believed it was possible to eliminate 50% of the inbred material without losing really superior lines. Because of early individuality of inbreds for their yielding capacity, Jenkins (9) points out that it is possible to top cross quite early in the selfing program.

Johnson and Hayes (11) employed the top cross method for predicting the combining ability of inbred lines of Golden Bantam in single crosses. All possible crosses between 11 lines of Golden Bantam were made. Each of the inbred lines was top crossed to the open-pollinated varieties Golden Bantam and Del Maiz. The poor combining lines when crossed together failed as a rule to produce high yielding single crosses. Crosses between good and poor combining lines gave a few high yielding single crosses, while a higher proportion of high yielding single crosses were obtained as a rule

from crosses between better combining lines. In an additional top cross study it was found that many replications of top crosses are needed and should be grown in several different localities, if combining ability of the lines is to be determined in one season.

Jenkins (8) studied combining ability of 11 inbreds in double crosses. Four methods of predicting double crosses were used and compared with 42 of the possible double crosses between these inbreds. Method (A) consisted of comparing the mean of 6 possible single crosses between the 4 inbred lines used in the double cross with the double cross itself; method (B) consisted of comparing the mean value of only 4 of the single crosses, excluding the 2 single crosses which entered into the double cross; method (C) consisted of comparing the average of the mean values for all of the single crosses involving each of the 4 lines in the double cross with the double cross; and method (D) consisted of comparing the average value of the top crosses of the 4 lines with the double cross. The correlation coefficients for yield by using the 4 different methods were .75, .76, .73 and .61 for methods A, B, C, and D, respectively.

In discussing method (B) Jenkins (8) stated, "In any double cross the genes of each of the four parental lines are united only with the allelomorphs of the two lines which entered the double cross from the opposite parent." At Minnesota extensive studies have shown that this method of prediction using the mean of the 4 non-parental single crosses is about as accurate as testing the actual double cross. Doxtator and Johnson (4) and Anderson (1) showed that a good relationship existed between the predicted double cross using method (B) and the actual double cross yield. Doxtator and Johnson (4) found significant differences in yielding ability in double crosses resulting from the use of the different single cross parents produced from four inbred lines.

Studies of F_1 crosses have been made by Wu (16) and Hayes and Johnson (6) in relation to genetic diversity. The inbreds used in these studies were obtained by the pedigree method of breeding from single crosses. The F_1 crosses were studied in three groups; the first group between inbreds selected from F_1 crosses between inbreds having no parents in common; the second group between inbreds which had one inbred in common in the parent single crosses; and the third group between inbreds of the same origin. The first and second groups of crosses were far superior to those of the third group in yielding ability. The first group of single crosses was considerably higher yielding on the average than the second group. Other data were presented that indicated combining ability was an inherited character.

Johnson and Hayes (12) give further evidence of the importance of combining ability of the inbred lines used in hybrid combination. Single crosses were made between inbred lines of different genetic origin. The inbreds were studied in single crosses in three groups, based on their top cross performance as high × high, high × low, and low × low. The low × low yielded much less in single crosses than low × high or high × high. High yielding single crosses were in about the same proportion from low × high combiners as from high × high combiners.

Eckhardt and Bryan (5) have shown the importance of genetic diversity in the parental single crosses of a double cross. Designating

inbreds from one variety as A and B, and from another variety as X and Y, they compared yields of the three possible double cross combinations $(A \times B)$ $(X \times Y)$, $(A \times X)$ $(B \times Y)$ and $(A \times Y)$ $(B \times X)$. The double cross comination $(A \times B)$ $(X \times Y)$ was consistently higher yielding than the other two. These results give further proof, therefore, that double crosses with inbreds from different origins would be higher yielding than those with inbreds all from the same origin.

MATERIAL AND METHODS

In order to facilitate making the single cross combinations, inbreds were selected with somewhat similar maturity. Two groups of inbreds were used and for convenience they will be called groups A and B.

Group A		Group B	
Inbred	Origin	Inbred	Origin
5	22-118	18	Bailey
6	Lancaster	21	Bailey
7	Lancaster	22	Bailey
8	Minn. 13	23	Bailey
14	Lancaster	26	Bailey
		27	Bailey
		31	Bailey

An attempt was made to select all members of each group of inbreds from the same origin. Only 3 out of the 5 inbreds in group A, however, were of the same origin. These 5 inbreds are of particular interest to the writer, as they include lines which have been selfed for several years and have shown good performance in previous crosses. Group B consists of 7 inbreds that have been selfed for only 5 generations previous to being used in the research. Each of these inbreds originated from a separate line, i.e., from a different self-pollinated plant of the Bailey variety. It will be noted that the origin of the inbreds in group A is entirely different from the inbreds in group B. The inbred numbers mentioned are those designations under which they appear in the Harrow inbred nursery.

Each inbred was top crossed with an open-pollinated variety, Harrow Golden Glow. This open-pollinated variety is unrelated to the varieties from which the inbred lines originated. The open-pollinated variety was used as the seed parent. In 1941 a yield trial of 8 replications was made of the 12 top crosses.

In 1940 three classes of single crosses were made, for the purpose of studying the effect of combining related lines among themselves, and of combining unrelated lines. All possible single cross pollinations were made among the inbreds of group A. These single crosses are called class I, and there was only enough seed for testing purposes in 8 out of the possible 10 crosses in this class. Class II contained 18 of the possible 21 single crosses that could be made in the B group. In class III there are 25 of the possible 35 single crosses, which could be made by crossing each inbred of group A with each inbred of group B.

The season of 1940 was rather unfavourable for ideal pollination and fertilization. Although seed was obtained from all of the 66 possible single crosses as originally planned, there was only enough seed for testing purposes in 51 cases.

As the number of varieties increases the randomized block design becomes less efficient due to increasing soil variation within the block. The lattice design recently described by Cox, Eckhardt and Cochran (2) is well adapted to testing a large number of varieties. It was desired to test the 51 single crosses plus the 12 top crosses together. A check open-pollinated variety, Harrow Golden Glow, was added to this group, making 64, and the test was carried out by using eight blocks of eight plots each. Four replications were used.

In all cases single row plots were used, 10 hills long. Plantings of 5 kernels per hill were made, and later seedlings were thinned to 3 per hill. At harvest the entire plot was husked and weighed. An average 10-ear sample from each plot was selected and weighed as well. The sample was dried and stored until such time as it could be shelled. At shelling time the air-dry weight of this sample was taken, the weight of shelled corn was obtained, and a duplicate moisture test was made on a composite sample from all replications for each cross. This information was used to determine the dry matter content and the shelling percentage. The acre yields were computed on the original field plot weights, using the dry matter content and the shelling percentage from the sample, and are given as bushels of shelled corn per acre at 14% moisture.

The outline for predicting double crosses from single cross data as set up by Millang and Sprague (14) was used. There was no punched card equipment available. Nevertheless a large number of copies of single cross data were mimeographed and each double cross was readily assembled and prediction values determined. This procedure eliminated extensive copying of data.

The corrected yield data of the single crosses were used in predicting. Predictions for yield were made for 118 double crosses by the method that has been accepted as most desirable. For double cross (A × B) (C × D), this consists of averaging the four non-parental single crosses, (A × C), (A × D), (B × C) and (B × D). There were three classes of predicted double crosses based on the origin of the inbred lines in the three respective single cross classes. The number of predicted double crosses in each class was 5, 54, and 59 in classes I, II and III, respectively.

A correlation study was made between the combining ability of inbreds in top crosses, and in single and predicted double crosses. The average top cross yield of the 2 inbred parents of the single cross was correlated with the single cross yield. For the predicted double crosses, the average of top crosses for the 4 inbreds was correlated with the average yield of the 4 single crosses used to predict the yield of the double cross.

The yields of the single crosses and the predicted double crosses were compared with check Harrow Golden Glow and placed in a frequency distribution based on − 7 to + 7 times the standard error of a difference, as calculated from the lattice analysis. The calculated standard error of

a difference was 5.8 bushels, and the class centres for plus and minus differences were 5.8, 11.6, 17.4, 25.2, 29.0, 34.8 and 40.6 bushels obtained by multiplying 5.8 by 1 to 7, respectively.

EXPERIMENTAL RESULTS

The calculated correlation coefficients for yielding ability in top crosses in relation to yielding ability in single and predicted double crosses are given in Table 1.

Table 1.—Correlation yields of inbreds in top crosses with their yields in single crosses and in predicted double crosses

	Single crosses	No.	Double crosses	No.
Class I	+ .0324	8	− .0369	5
Class II	− .1719	18	− .2032	54
Class III	+ .4872*	25	+ .3286*	59

* Exceeds the 1% level of significance.

In class I both the number of single crosses and predicted double crosses were small and the *r* value showed that there was no correlation. In class II the number of single and predicted double crosses was much larger, but still there was no correlation. In this study there was no significant relationship between combining ability of inbreds obtained by averaging their top cross yields, and the performance of these inbreds in single and predicted double cross yields, when inbreds were obtained from the same origin.

Class III, however, consisting of studies of crosses between inbred lines of different origins, gave a positive and highly significant correlation for yielding ability of inbreds in top cross combinations, in relation to their yielding ability in single crosses and predicted double crosses. A correlation as high as this would be expected to be due to chance less than once in 100 times. While the coefficients were highly significant, they were too small to be of great value in predicting the expected performance, in single crosses and predicted double crosses, from the yields of inbreds in top crosses.

The data from the three classes of single crosses were combined together in a single frequency table, giving opportunity to compare the yielding ability of single crosses with the check. The single crosses were classified into groups, on the basis of the combining ability of the parents in top crosses. The top cross yields from 70 to 82 bushels were considered as low combiners, while those yielding from 83 to 107 were considered as high combiners. The single crosses were then placed in three groups according to the manner in which they combined, low × low, low × high, and high × high. The computed standard error of a difference by an analysis of variance in the lattice was 5.8 bushels. Each of the crosses was then compared with the check, open-pollinated variety, Harrow Golden Glow, by obtaining the difference in yield between the check and the cross con-

cerned, and entered in the correct frequency distribution with class centres 0, + or − 1, + or − 2, etc. The 0 class contained all deviations lying from 0 to plus or minus 2.9, class 1 from 3.0 to 8.8, class 2 from 8.9 to 14.7, etc. The data are summarized in Table 2.

The 11 single crosses from inbred parents classified as low combiners gave a mean deviation of − 2.27 ± .43, and the 32 single crosses between parents classified as low and high combiners, respectively, gave a mean deviation of .53 ± .54. The difference between these two groups is 2.80 ± .69. There is (11 + 32) − 2 = 41 degrees of freedom in this case, and the *t* value at the 1% point for this number of degrees of freedom is 2.71. The standard error, .69 × 2.71 = 2.08, and a difference as great as this, for 41 degrees of freedom would be expected to be due to chance less than once in 100 times and is highly significant. Therefore, the difference of 2.80 ± .69 between the two above groups is highly significant.

TABLE 2.—SUMMARY OF FREQUENCY DISTRIBUTION OF SINGLE CROSS YIELDS WHEN COMPARED WITH THE CHECK VARIETY, HARROW GOLDEN GLOW, IN RELATION TO THE TOP CROSS COMBINING ABILITY OF THEIR INBRED PARENT

Type of cross	Class centres of plus or minus 1 to 7 times the standard error of a difference															Total	Mean class
	−7	−6	−5	−4	−3	−2	−1	0	1	2	3	4	5	6	7		
Low × low				2	3	4	1		1							11	−2.27 ± .43
Low × high	1		1	2	2		4	7	3	2	3	6			1	32	+0.53 ± .54
High × high					1	2	1	1		2	1					8	−0.13 ± .79

The difference between low × low and high × high is 2.14 ± .92. The degrees of freedom in this case are (11 + 8) − 2 = 17, for which the *t* value at the 5% point is 2.11. The standard error, .92 × 2.11 = 1.94, is less than 2.14. This difference of 1.94 for 17 degrees of freedom would be expected to be due to chance alone less than once out of every 20 times and is significant. The difference of 2.14 ± .92 exceeds the 5% point and therefore is significant.

The 8 single crosses between parent inbreds of high combining ability gave a mean deviation of − .13 ± .79 and the 32 single crosses between inbreds in which one inbred was classified as low and the other as high gave a mean deviation of + .53 ± .54. The degrees of freedom are 38, for which the *t* value at the 5% point is 2.02. The difference between these two groups of .66 ± .95 is not significant.

The data from these 51 single crosses, compared on the basis of the combining ability of their inbred parents, indicate that high × high and low × high are about equal in producing high yielding crosses. Although the number of crosses is small, low × low combiners yielded distinctly less than low × high and high × high. The 11 low × low single cross combinations were distributed among the three classes of single crosses; 1, 5 and 5 in classes I, II and III, respectively.

The three classes of single crosses and predicted double crosses were placed in a frequency distribution. The calculated standard error of a difference of 5.8 bushels was used and the procedure followed was the same as in Table 2. The summary of these results classified for yield is given in Table 3.

The 8 single crosses of class I gave a mean deviation of $-2.25 \pm .59$, and the 25 single crosses of class III gave a mean deviation of $+1.24 \pm .58$. The number of degrees of freedom is 31, for which the t value at the 1% point is 2.74. The difference of $3.49 \pm .81$ between these two classes is highly significant. The degrees of freedom, when comparing classes II and III, are 41, for which the t value at the 1% point is 2.71. The difference of $2.18 \pm .80$ between these two classes is also highly significant.

The 54 predicted double crosses in class II gave a mean deviation of $-1.06 \pm .15$ and the 59 predicted double crosses in class III gave a mean deviation of $+1.24 \pm .21$. The number of degrees of freedom is 111, for which the value of t at the 1% point is 2.63. The difference of $3.30 \pm .26$ between these two classes is highly significant. The number of degrees of freedom for comparing classes I and II of the predicted double crosses is 62, for which value of t is 2.66 at the 1% point. The difference of $3.44 \pm .30$ between these two classes is also highly significant.

TABLE 3.—FREQUENCY DISTRIBUTION OF SINGLE CROSS AND PREDICTED DOUBLE CROSS YIELDS WHEN COMPARED WITH THE CHECK VARIETY, HARROW GOLDEN GLOW, IN RELATION TO THE ORIGIN OF THE INBRED PARENTS

	Class centres of plus or minus 1 to 7 times the standard error of a difference															Total	Mean class
	−7	−6	−5	−4	−3	−2	−1	0	1	2	3	4	5	6	7		
Single cross																	
Class I			1		3	2		2								8	$-2.25 \pm .59$
Class II	1			2	2	1	4	4	3			1				18	$-0.94 \pm .55$
Class III				2	1	2	2	3	1	4	4	5			1	25	$+1.24 \pm .58$
Predicted double cross																	
Class I					2	2	1									5	$-2.20 \pm .22$
Class II				1	2	19	14	13	5							54	$-1.06 \pm .15$
Class III						2	9	9	11	14	9	5				59	$+1.24 \pm .21$

In both the single crosses and the predicted double crosses those crosses in class III which are between unrelated inbreds significantly outyielded those between related material. Although only 3 out of the 5 inbreds used in class I are related, there appears to be sufficient evidence to verify this fact in comparing the yielding performance of the crosses in class II with those in class III. In both the single crosses and the predicted double crosses the number in class I was too small to be of a great deal of importance.

In class III, 60% of the single crosses and 66% of the predicted double crosses outyielded the check, open-pollinated variety. Comparing this with class II, 22% of the single crosses and 9% of the predicted double

crosses yielded above the check. This high percentage of high yielding crosses from unrelated stocks, as shown by these data, would indicate the distinct value in combining lines of diverse genetic origin.

SUMMARY

1. A study was made of the suitability of the top cross test as a method of determining the relative combining ability with respect to yield of inbred lines.

2. A comparison was made of the effect of inbreds from similar and diverse genetic origin in single crosses and predicted double crosses.

3. There was a positive and highly significant correlation between top cross yields of unrelated inbreds and their yields in single crosses and predicted double crosses. No correlation existed where related inbreds were used.

4. The yields of single crosses from inbred lines classified on the basis of their performance in top crosses were essentially the same, whether the crosses were made between high × high or high × low combiners. Low × low combiners yielded distinctly less than low × high or high × high.

5. In this study the yield of single crosses and predicted double crosses among unrelated inbreds was significantly higher than the yield of those crosses between related inbreds. These results indicate the feasibility of selecting inbreds for use in double crosses from diverse genetic origin.

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MALTING QUALITY OF CANADIAN BARLEYS

IV. A SUMMARY OF INFORMATION OF SPECIAL INTEREST TO PLANT BREEDERS[1]

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INTRODUCTION

A logical program designed to develop barley varieties of improved agronomic and malting value can be based only on a clear conception of the goal to be achieved, a thorough knowledge of the characteristics of the available parent material, and adequate means of rapidly assessing the value of new hybrid lines and selections. From the agronomic standpoint these conditions can be met to a very large extent, but from the malting viewpoint the existing situation is not entirely satisfactory.

Malting quality in barley is not easy to define. It depends on the malting method to be adopted, on the brewing process in use, and on the type of beer required. These conditions differ in different countries, and even within the same country, so that no single definition of malting quality can be widely applied. For this reason no universally acceptable definition of malting quality has been devised, and such definitions as do exist are either minutely qualified or couched in general terms dealing largely with the superficial characteristics of the barley and the malt made from it.

There is good reason to believe that in each country a system of malting and brewing has been developed which is well adapted to the type of barley traditionally grown in the country. It seems pertinent to interject that it also appears that the type of barley most widely grown in any country is also the type best suited agronomically to the prevailing environmental conditions. Broadly speaking, when the raw materials and the processing method have been standardized, the end product also becomes standardized and when the consumer acquires a taste for this product there is set up an equilibrium which many interests strive to maintain.

Any widespread attempt by plant breeders to improve the agronomic characteristics of the barley may have important effects on this equilibrium by changing the malting characteristics of the barley grown in the country. Theoretically, a change in malting characteristics may represent an improvement in the malting quality of the barley. In practice, any considerable change in malting characteristics is likely to be unpopular with maltsters and brewers since it will probably involve changes in

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processing methods, may increase production costs, and may well create more fundamental difficulties not easily foreseen. In these circumstances, a conservative line of advance, eschewing any abrupt change, seems advisable. The immediate goal of the plant breeder may well be improvement in such important agronomic properties as yield and disease resistance without change in malting characteristics.

The processes used in the Canadian malting and brewing industries are adjusted to make best use of parcels of the variety O.A.C. 21, originating in Canada under environmental conditions producing barley having a protein content equal to, or slightly lower than, the Canadian average. Any variety which is closely similar in its malting characteristics to O.A.C. 21 will thus have acceptable malting quality from the Canadian viewpoint, whereas any variety which differs appreciably from O.A.C. 21, in any important barley, malting or malt property, will probably be considered inferior. In this connection it should be mentioned that differences from O.A.C. 21 which appear to represent improvements must be given careful consideration. Thus, though the maltsters do not want small kernels, it is by no means certain that varieties with large kernels will prove satisfactory since such kernels may prove difficult to modify within the six-day germination period commonly used on this continent. Again, though an increase in the extract yield of malt appears generally desirable, it might be brought about in undesirable ways. For instance, an increase in extract yield resulting only from an increase in the nitrogen compounds of the wort might well lead to brewing difficulties since the percentage of nitrogen in Canadian worts is already quite high.

The selection of O.A.C. 21 as a standard variety was originally made on the recommendation of Canadian maltsters. When the Canada Grain Act was revised in 1929 the grades for barley were changed and official recognition was given to O.A.C. 21 by requiring that only varieties equal in malting quality to O.A.C. 21 should be permitted to enter the upper grades of six-row barley. Additional practical experience and many laboratory studies covering a wide field of investigations have upheld the wisdom of this choice. When compared with other six-row varieties grown in Canada, over a wide range of growing conditions, and when malted under the system used in this country, O.A.C. 21 has consistently yielded the best malt as judged by hand evaluation, physical and chemical analyses, and performance in the brewery. Briefly, it may be said that the balance which this variety exhibits between the quantities of major barley constituents, and between the activities of the various groups of enzymes, together with its comparatively high degree of stability under different environmental conditions, enable it to produce a mellow, well modified malt within the six-day germination period used in commercial malt houses in Canada.

It is possible that this summary of existing conditions puts the plough before the tractor. Perhaps it would be better to say that the malting and brewing processes used in Canada are ideally suited to the variety O.A.C. 21. It may be that with different processes some other variety might show to better advantage than O.A.C. 21. Some light was shed on this matter by a series of investigations (1, 2, 4, 13) in which several Canadian varieties were malted by different methods. Without going

into the results of these experiments in detail, it may be said that they served to confirm the opinion that it is improbable that any variety of barley now grown in Canada, with the exception of certain varieties officially listed as equal in malting quality to O.A.C. 21 (Mensury, Mensury Ottawa 60 and Olli), will produce higher quality malt that O.A.C. 21 under any system of malting which does not involve an increase in malting costs. For example, with a longer and slower germination period, certain varieties with larger kernels and lower enzymatic activity than O.A.C. 21, can probably be made to yield better malts than the latter variety. Such malting conditions, however, decrease the capacity of the malt house and increase malting costs appreciably.

If O.A.C. 21 be accepted as the standard variety for Canada, and this seems necessary in view of its official status and the limitations of our existing knowledge of what constitutes malting quality, a considerable simplification of practical aims and procedures results. The aim will be to produce a variety closely similar in malting qualities to O.A.C. 21 but with higher yielding capacity, disease resistance and other desirable characteristics. The procedure, since environmental factors also affect malting quality, must be that of comparing the barley and malt properties of samples of O.A.C. 21 and new varieties, grown under identical environmental conditions in properly controlled and replicated field plots.

The prospects for the production of new varieties of improved agronomic quality, and with satisfactory malting qualities, by crossing carefully selected parent varieties, seem promising. However, it is apparent that a wise selection of parents cannot be made unless the malting characteristics of these are known. It is true that a haphazard crossing of parents, selected merely on the basis of agronomic characters, might lead to the production of a variety of good malting quality, but such a procedure leaves more to chance than is necessary under existing conditions. A considerable body of information has been obtained during the past few years on the malting quality of the principal varieties in use in barley breeding work in Canada. Data on 19 of these were published early in 1939 (8). Since that time studies have been continued on 17 of these varieties and on 11 others (9). Moreover, additional information has been obtained by investigating a considerably greater number of barley and malt properties (5, and other papers in that series). Comprehensive sets of malting data are thus available for 28 varieties.

The interpretation of the data for these varieties is not easy. It appears to involve not only a comparison of the actual values given by different varieties for each individual property, but also a consideration of the internal balance between various properties within one variety. The matter is further complicated by the effect of environment on malting quality and by interactions between varieties and environments with respect to each property of the barley or malt. In practice, comparisons must generally be confined to average values representing the analyses of samples grown over a representative range of environments: a sound procedure, since in Canada, where regional licensing for distribution is not permitted, a variety must be judged by its average performance. Interactions between varieties and environments can be neglected except in so far as these condition judgment as to what may or what may not

be considered a significant difference between varietal means. This again seems sound, since experience has shown that when a difference between varieties is of sufficient magnitude to be of practical importance, it can generally be established that it is also significant from the statistical viewpoint.

As a practical approach to the problem of selecting varieties equal in malting quality to the standard, it may safely be assumed that definite inferiority with respect to any important property may be considered as adequate grounds for rejection. This practice has long been in use for the selection of wheats equal in milling and baking qualities to the Canadian standard variety, Marquis. When definite inferiority with respect to one important property is not established, some leeway may be allowed. Thus a slight inferiority in certain respects may be offset by advantages in others. However, caution must be exercised particularly in assessing what appear superficially to be advantages.

In a later section of this paper the Canadian barley varieties, on which information is available, are classified with respect to malting quality. An attempt has been made to avoid detailed discussion of individual barley and malt properties. These discussions, though they may be intelligible and informative to the malting expert, must generally be so hedged with qualifying statements as to obscure the principal characteristics of the various varieties. It, therefore, seems best to confine the description of individual varieties to general statements concerning their chief advantages and deficiencies. For this purpose it did not appear necessary to repeat or summarize malting data which have been published elsewhere, or to report new data which will appear in other papers now in preparation.

When the plant breeder has selected the parent varieties and made the crosses, his work has just begun. Although the cereal chemist can make a contribution to this initial phase of the breeding program, it is in the latter stages of the work that his aid is most required. Thus, it should be possible for the malting chemist to be of considerable assistance to the plant breeder in the selection from a hybrid population of those lines which merit further study and development. Although in early generations, and with large populations, selection can be made most effectively by consideration of agronomic characteristics, there frequently comes a time when a further reduction in the population must be made which cannot be based on observable differences in the growing plant or threshed grain. Thus a plant breeder might have at hand 100 lines apparently of equal value but might be able to include only 10 of these in extensive yield trials. At this stage he might properly seek the assistance of the chemist so that the 10 lines carried forward might be those having the most promising malting characteristics.

Until recently it seemed necessary to make malting tests on all 100 samples. This is a time-consuming process. Canadian experience suggests that four men in an adequately equipped laboratory with malting equipment for 24 samples, can make, analyze, and report on 24 malts per week. Thus 100 samples require approximately 4 man-months of labour. The difficulty and cost of making tests of new lines at an early stage of development, for several plant breeders, is thus apparent.

It was this situation which brought about studies of the relations between barley and malt properties, and resulting attempts to devise methods of predicting the latter from data on the former (7, 11, 12, 15). Even if prediction is based on such a complex determination as that of barley extract, the number of samples which one man can test is about 8 times greater than the number he can malt and analyze in the same time.

It should be borne in mind that a complete solution of the prediction problem, though desirable, is not essential. Returning to the example of the plant breeder who has 100 lines of which only 10 can be carried forward into yield trials, let us suppose that 10 out of the 100 have some merit from the malting standpoint. If the selection of 10 from a hundred is made without consideration of malting properties, this 10 would contain, on the average, only 1 line with malting possibilities. On the other hand, if a prediction method were available which was 70% accurate, the 10 lines selected might be expected to contain an average of at least 7 lines with malting possibilities, and the chance of obtaining a new line with high yielding capacity and adequate malting quality would thus be appreciably increased.

In previous papers (5, and preceding parts) the relations between certain malt properties and each of a number of barley properties were examined and the possibilities of predicting the former from data on one or more of the latter were discussed. It was pointed out, however, that a wide use of various prediction equations for malt properties was not expected. In practice, the use of these equations is cumbersome and presents few advantages. Their utility lies rather in that they serve to bring to light the various associations and fundamental relations which exist between barley and malt properties. With a knowledge of these it then becomes possible to assess the significance of varietal differences with respect to certain barley properties, and thus to devise a system of comparatively simple barley analyses, rapidly made, which will serve for the preliminary selection from hybrid populations of lines showing promise of good malting qualities. The progress which has been made along these lines is discussed in the last section of this paper.

INTERPRETATION OF ANALYTICAL DATA ON BARLEYS AND MALTS

It is with some trepidation that the authors have ventured to include in this paper a section on the interpretation of analytical data on barleys and malts. Opinions on this subject may differ widely. In the first place, barley and malt characteristics which are considered quite satisfactory in one country may be unsatisfactory in another country in which different raw materials and processing methods are used. Accordingly, literature published in countries other than Canada, particularly that dealing with two-rowed barleys, has only a limited bearing on the interpretation of Canadian data. Again, many of the hypotheses relating to the interpretation of data can only be adequately tested by means of investigations involving brewery trials and subsequent examination of the resulting beer. Such studies are unwieldly and almost impossible

to carry out on a commercial scale, and small-scale facilities for replicated brewing trials are not available in Canada nor fully developed in other countries.

These difficulties notwithstanding, the authors of this paper, having undertaken most of Canadian work on malting barleys during the past few years, fail to see how they can escape the responsibility for putting on record their opinions on the interpretation of malting data, however tentative these opinions may be. It must be borne in mind that the opinions given are intended to apply to Canadian conditions only and may be modified from time to time as the results of further investigations become available.

Since almost all of the malt made in Canada is used for the production of beer, the malting quality of varieties must be considered chiefly from the brewer's viewpoint. Beer is made only from that part of the malt which is extracted when the malt is ground and mashed with water under certain specified conditions of time and temperature. The mash is subsequently filtered yielding the clear wort which is fermented to produce beer. The quantity and quality of the wort or extract yielded by a malt are thus the principal criteria of malt quality.

The extract yield of a malt depends largely on the quantity of potentially extractable material in the barley. This can be determined directly by an empirical method which involves mashing the ground barley with water and adding enzymes which convert starch to sugars. The starch attacking enzyme preparation also contains other enzymes which, together with enzymes present in the barley, attack other constituents of the kernel. Although the determination of barley extract is empirical and comparative rather than absolute, experience has shown that it gives very useful information when applied to samples of different varieties. Additional information can be obtained by making a separate determination of starch, the barley constituent which contributes the largest portion to the malt extract. The determination of the salt-soluble protein in the barley is also useful in this connection.

The second factor which affects the extract yield of a malt involves the degree to which the potentially extractable material is made available during the malting and mashing processes. The major portion of the barley consists of insoluble compounds among which the starch and proteins are of principal importance. To make malt the barley is germinated and grown under controlled conditions for six days. During this period enzymes are liberated or generated in the kernel, principally at the germ end and in the peripheral cell layers, spread throughout the kernel and bring about a partial hydrolysis of cell walls, carbohydrates, proteins and other compounds. Some of the soluble compounds thus produced, such as sugars and amino acids, are transported to the roots and growing acrospire where they are resynthesized into insoluble compounds. When the malt is subsequently dried and polished, the roots are discarded and with them there is lost a small portion of the potentially extractable materials of the barley kernel. An additional and somewhat greater loss takes place as a result of respiration during the germination process.

When the malt is dried the development of enzymes is stopped, enzymatic activity is brought to a standstill, and a considerable destruction of enzymes takes place. The enzymes again become active when the ground malt is mashed with water during the first part of the brewing process. It is at this stage that the principal transformation from insoluble to soluble compounds takes place; starches and portions of other carbohydrates are hydrolysed by enzymatic activity into dextrins and sugars while the more complex proteins are broken down into polypeptides and amino acids. Both the quantity of wort solids (extract yield) and the quality of the wort are affected by kinds and extents of the hydrolytic processes which take place in the mash. Some control can be effected by changing the time-temperature relations during the mashing process but the kinds and activities of the enzymes present in the malt are of prime importance.

If a broad generalization is permissible, it may be said that malting and mashing can be considered as parts of the same process, having as its objects the development of enzymes and their utilization in transforming insoluble barley constituents into soluble wort constituents. The enzymatic activities which can be developed during the malting and mashing processes thus appear to be important attributes of malting quality.

The determination of the enzymatic activities of different varieties of barley is no easy matter. Most of the enzymes do not appear to be present in the barley and may well be actually formed during the germination process. Alternatively, they may be present in the barley in reduced quantities or in a partially or wholly inactive state. As a consequence, it is almost essential to malt the barley before attempting determinations of enzymatic activity. However, even this does not solve the problem entirely. Methods for the determination of many enzymes are not fully developed, certainly lack standardization, and are frequently too laborious and time-consuming for routine studies.

One exception to this generalization exists. The enzyme which is mainly responsible for converting starch to sugar, beta-emylase, is present in the barley in a partially combined or inactivated form. It can be liberated or activated by papain and its potential activity in the malt can thus be estimated with a fair degree of accuracy (11, 12). The value of this ability to determine beta-amylase activity by analysis of the barley, without resort to malting, will be obvious.

When the malt has been made diastatic activity (beta-amylase) and starch liquefying activity (alpha-amylase) can be determined fairly readily (14). The combined effectiveness of these enzymes, in relation to their natural substrata, can also be determined by means of an autolytic digestion process (14). A similar method yields some information on proteolytic activity (6). Various other methods are available for studying the proteolytic enzymes and certain other enzymes but these are relatively complex and have not yet been applied to the study of Canadian varieties.

Certain indirect measurements of enzymatic activity are also available. There is some evidence of an inter-varietal relation among various enzymes so that a variety which is high in one enzyme is frequently high in others (5). The determination of activated diastatic activity in the barley thus takes on added significance. It also appears that a relation exists between

enzymatic activities and salt-soluble protein which leads to the hypothesis that varieties that are high in salt-soluble barley protein also tend to be high in enzymatic activities.

When barley is germinated and grown under standard conditions, as in the laboratory malting test, the growth rate is related to general enzymatic activity. That a relation of this sort must exist is self-evident since rate of growth depends on the activity of the respiratory enzymes and those which make nourishment for roots and acrospire available by breaking down starch, proteins, etc. into soluble compounds which can be transported to the growing parts of the young plant. The malting tests provide only crude measurements of growth rate, namely. the determinations of total malting loss and of sprouts. Nevertheless these determinations provide useful information on the enzymatic activities of different varieties.

The determination of wort nitrogen gives supplementary information on proteolytic activity. It appears that the amount of nitrogen in the wort depends partly upon the amounts of soluble nitrogen compounds in the barley and partly upon the activities of the proteolytic enzymes developed during the malting process. The relations are not simple (6) so that all one can say is that varieties which tend to contain larger amounts of salt-soluble nitrogen also tend to produce malts of higher proteolytic activity which yield worts of higher nitrogen content.

The determination of malt extract provides a quantitative measurement of the amount of material in the malt which is available for making beer. If the extract yield of a variety is lower than average it will generally be found that the variety is low in enzymatic activity or in potentially extractable barley constituents. Bearing in mind the foregoing discussion, it will be clear that when fairly complete analyses of the barley and malt are available, it is almost invariably possible to determine the particular defects responsible for a low yield of malt extract.

Adequate methods of assessing wort quality are being developed to a stage at which they can be used in routine work. During the course of the laboratory determination of extract some information on quality can be obtained by measuring the colour and clarity of the wort, and the speed with which it filters. The methods used are neither precise nor objective and their usefulness is thus limited. An important and relatively precise index of quality is provided by the determination of wort nitrogen as a percentage of total wort solids (8). If this ratio deviates far from normal values, trouble may be expected in the brewing process.

Studies of additional methods of determining wort quality have been carried out. A precise method exists for the determination of the turbidity of the wort both immediately after preparation and on prolonged standing. Turbidity appears to be an index of the chemical modification which has taken place during the malting and mashing processes. The determination of the viscosity of the wort is also useful since it is largely dependent on the dextrin-sugar ratio. Finally, experiments have been carried out with the degree of attenuation of the wort on fermentation with yeast. This determination provides a measure of the amount of wort solids which can be fermented to produce alcohol. It appears that varietal differences

exist with respect to all these properties and that their determination provides additional information on varietal differences in malting quality (10).

In spite of the limitations of available methods, and the fact that these have not all been applied in routine studies of Canadian varieties, there is little reason to believe that lack of detailed and precise information on wort quality creates a serious difficulty. The quality of the wort depends on the kinds and amounts of the compounds dissolved in it. These depend in turn upon the kinds and amounts of the barley constituents and the way in which these are modified by enzymic action during the malting and mashing processes. Thus if we can assure ourselves that the barley constituents are satisfactory and that enzymatic activity is adequate we may be relatively certain that the quality of the wort will also be satisfactory.

In addition to the chemical properties discussed above, there are a number of physical properties of the barley kernel which must be taken into account. The importance of certain of these, however, results from their effect on the chemical processes which take place during malting.

For Canadian conditions, the barley kernels should be of medium size, weighing about 31 to 32 g. per 1000, and should be short and plump rather than long and thin. While larger kernels normally have a lower percentage of hull and thus contain higher percentages of starch and other extractable materials, they do not modify readily in the six-day germination period used in Canadian malt houses. Modification, as has been pointed out previously, is the result of the activity of the various enzymes which are released or produced when the kernel germinates. The enzymes are concentrated mainly at the germ end of the kernel and secondarily in its outer layers. It takes time for them to spread throughout the kernel, particularly when this is long or large, and the process cannot be forced. If it is, excessive enzymatic activity and over modification takes place at the germ end while the tip still remains 'steely'. The percentage of heavy grade barley should be as high as possible since small or thin kernels are least useful for malting purposes and uniformity of kernel size is highly desirable.

The hull of the barley should be reasonably thin but tough and closely applied to the kernel. The hull yields little extractable material but is useful in producing a filter bed in the mash tun. If the hull is too thick the extract yield of the malt will be low. If it is too thin and brittle it will break up during grinding and fail to provide an adequate filter bed. When the hull is loosely held, part of it tends to break off with the awn leaving an unprotected tip on the kernel. Moreover, during the germination period as the acrospire grows it may split the hull, thus exposing the acrospire which may be broken off and stop growing. A ragged unsatisfactory malt will thus be produced. The hull should remain intact throughout the whole malting process thus protecting the kernel from damage, both physical damage and that caused by fungi and moulds.

A high and even germination rate is, of course, an important characteristic of malting barley. Germination appears to be controlled mainly by environmental factors (e.g. frost) and it is only infrequently that there

is evidence of a varietal effect on this character. In the malting process those kernels which fail to germinate do not modify and consequently serve to lower the extract yield of the malt. Uneven germination results in uneven modification and has the same effect since a lowering of extract yield can result not only from under modification but also from over modification. Without adequate modification malt is less friable than is desirable with the result that it fails to grind uniformly and does not release all of its potential extract during the mashing process.

Although the suitability for malting purposes of kernels of any new variety can generally be determined by inspection, two quantitative determinations bearing on this point are also useful. These are the determinations of 1000-kernel weight and of percentage of heavy grade barley. To be satisfactory, 1000-kernel weights should not differ, on the average, by more than about 1·5 g. from that of the standard variety O.A.C. 21. The percentage of heavy grade barley is determined with a ring grader. The spacing between the rings increases gradually from 3/64 inch at one end to 5/64 inch at the other end and three fractions, discard, medium grade and heavy grade, are separated. Since the ring openings are long and narrow the determination penalizes those varieties which have high percentages of thin kernels.

Although it is difficult to summarize the information given in this section, it will be apparent that in order to be satisfactory for malting purposes a barley variety must have certain important groups of characteristics. It must be high in potentially extractable barley constituents. Enzymatic activities must be well balanced and must so develop during a 6-day germination period that the potential extract yield of the barley is realized during the mashing to produce a wort containing the normal proportions of the more important hydrolytic products of the malt. It is also important that the physical properties of the barley kernel should be satisfactory with respect to size, shape and hull characteristics. The standard Canadian malting variety, O.A.C. 21, is satisfactory in all these respects, and it may be assumed that any new variety of barley which is closely similar to O.A.C. 21 in malting properties will be quite acceptable to Canadian maltsters.

A SUMMARY OF INFORMATION ON THE MALTING QUALITIES OF INDIVIDUAL VARIETIES

The Canadian plant breeder, who is interested in developing superior malting barleys, has as his goal the production of a variety combining malting quality, equal or superior to O.A.C. 21, with high yield, disease resistance, strong straw and other desirable agronomic characteristics. Popular demand appears to require the introduction of smooth awns and earliness is also desirable for Western Canada, since it has been shown that the more northerly areas are more suitable for the production of malting barley.

It is apparent that the development of an ideal variety is no simple matter and the plant breeders are forced to use varieties in their programs that have serious defects from the malting viewpoint. Fortunately, the breeding material available in Canada appears to possess all the elements

required to produce a superior variety. However, the task of combining the desirable attributes and eliminating malting deficiencies is a complex problem which can not readily be solved, if at all, by means of simple crosses. Accordingly, a program starting with simple crosses and developed by double crosses and back crosses has been under way for some years in Canada.

It is one of the functions of the malting chemists to obtain data on the malting qualities of the named varieties available as breeding materials. In previous papers in this series (3, 8, 9) detailed data have been presented for 28 varieties. However, as this data is not easily interpreted, an attempt has been made in the present paper to discuss the malting qualities of each variety in general terms, comparing it with O.A.C. 21, and pointing out its main advantages and deficiencies. Comments are confined to three groups of characteristics: the potential extractable barley constituents, enzymatic activities, and physical characteristics of the kernel. It is thought that these brief descriptions will provide a ready reference for plant breeders who are interested in selecting additional parent varieties for introduction into their breeding program. When more detailed information and actual data on barley and malt properties are required reference may be made to other papers (3, 6, 8, 9, 10, 12, 14).

The individual varieties are discussed in four groups: six-rowed rough-awned varieties, six-rowed smooth-awned varieties, two-rowed rough-awned varieties and two-rowed smooth-awned varieties. With the exceptions of O.A.C. 21, which is described first, and Hannchen, which is described first in the third group, the varieties are discussed in alphabetical order within each group.

SIX-ROWED ROUGH-AWNED VARIETIES

Most of the Canadian-grown members of the group are varieties of the Manchurian type (Trebi is the chief exception). A considerable range of malting qualities is represented and there are wide difference in yielding capacity, disease resistance and other important agronomic characteristics. There is perhaps no special reason for grouping all these six-rowed rough-awned varieties together. The procedure is adopted principally because it is convenient to group the varieties according to number of rows and then to subdivide according to awn-type.

O.A.C. 21.—This, the standard variety, produces a satisfactory yield of heavy grade kernels, which are of medium size and medium nitrogen content, over a wide range of environmental conditions. O.A.C. 21 is of medium starch content, but appears relatively high in barley extract and in salt soluble nitrogen. Its diastatic activity and wort nitrogen content are also quite high. The malt extract of O.A.C. 21 is very little lower than its barley extract, despite the losses of soluble material during malting. It thus appears that the supply of enzymes in this variety is adequate to produce a mellow well modified malt which yields a maximum of extractives.

Brio.—The yield of heavy grade kernels and nitrogen content of this variety compare favourably with those of the standard, but it is somewhat

low in kernel weight. The malt extract yield and wort nitrogen content of Brio are satisfactory, but it tends to be slightly low in diastatic activity.

Chevron.—This variety is faulted in all three major barley characteristics, as it is very high in nitrogen content, and very low in percentage heavy grade kernels and in kernel weight. These deficiencies are reflected by a low malt extract, even though this variety appears well supplied with enzymatic activity.

Gartons.—There are distinct similarities between the kernel characteristics of Chevron and Gartons, though the latter does not differ as much from O.A.C. 21 as the former. Gartons is, however, definitely faulted in kernel characteristics. It also is low in malt extract, high in nitrogen content and somewhat deficient in enzymatic activities.

Lapland.—This variety is not satisfactory for malting owing to low yield of heavy grade kernels and low kernel weight. However, its malt extract and enzymatic activities compare favourably with O.A.C. 21.

Mensury.—The characteristics of this variety appear to be identical with those of O.A.C. 21 in every respect and it is considered fully equal to the standard in malting quality.

Olli.—The tendency of Olli to produce a low percentage of heavy grade kernels and kernels of light weight are its main faults. It is high in starch content and in barley extract. This may be due to its thin hull. Olli is also high in salt soluble nitrogen, enzymatic properties and malt extract. It appears to be a promising variety, but, because of its tendency to produce small thin kernels, its final worth has yet to be determined.

Peatland.—This variety appears intermediate between Chevron and Gartons in kernel characteristics and it is faulted in percentage heavy grade barley, kernel weight and nitrogen content. Although Peatland is about equal to O.A.C. 21 in starch content and barley extract, it does not produce as much malt extract as the latter. This is due mainly to its high barley nitrogen content, but is also due in part to enzymatic deficiencies. It should also be noted that Peatland shows a very wide range in nitrogen content with changes in environment.

Pontiac.—Although the barley characteristics of this variety are similar to those of O.A.C. 21, it is lower than the standard in salt soluble nitrogen, starch and barley extract. These deficiencies cause Pontiac to be lower than O.A.C. 21 in malt extract and wort nitrogen, therefore, it is not considered equal to O.A.C. 21 in quality.

Trebi.—The low nitrogen and high starch contents of this variety are desirable, as is its high percentage of heavy grade barley. However, its kernel weight appears too great for proper modification. It is somewhat low in malt extract and very low in wort nitrogen content. The supply of enzymes in Trebi appears fairly satisfactory so that its failure to modify properly may be attributed to kernel structure. In the large long kernel the enzymes do not develop uniformly throughout the endosperm in the 6-day germination period used in Canada. Trebi is also faulted for its thick coarse hull and uneven germination. This latter fault is a further impediment to proper modification. Trebi is, therefore, definitely inferior to O.A.C. 21 in malting quality.

SIX-ROWED SMOOTH-AWNED VARIETIES

The wide-spread introduction of smooth-awned varieties occurred in the United States before the repeal of the Eighteenth Amendment. At that time there was little interest in the malting quality of barley. The smooth-awned varieties are almost all derived from Lion, a variety which appears to have had nothing to commend it from the malting viewpoint. Experience has shown that the task of eliminating the deficiencies of Lion from its progeny is formidable. Nevertheless, since farmers and plant breeders are convinced of the desirability of obtaining a smooth-awned variety of satisfactory malting quality, the smooth-awned varieties must hold an important place in any breeding program and the malting qualities of these types must be adequately studied.

Brandon 216.—The exceptionally low yield of heavy grade kernels and low kernel weight of Brandon 216 are undesirable, but it contains a high percentage of extractives. It gives a satisfactory malt extract yield and compares favourably with the standard in enzymatic activities; however, because of its kernel size, this variety is definitely inferior to O.A.C. 21 in malting quality.

Byng.—With the exception of being somewhat deficient in salt soluble nitrogen, Byng may be considered satisfactory with respect to barley properties. However, malts from this variety are low in diastatic power and wort nitrogen content. These deficiencies indicate that Byng does not modify properly and as a result this variety cannot be considered as promising for malting.

Newal.—The starch content of this variety is lower than that of O.A.C. 21, although the barley extract values for both varieties are similar. Despite its high diastatic activity Newal does not produce its potential extractives as malt extract; this indicates a deficiency in modification which may be due to an inadequate development of proteolytic enzymes.

Nobarb.—The barley characteristics of this variety are satisfactory, with the exception that it is low in diastatic activity and salt soluble nitrogen. A deficiency in enzymatic development is the most probable cause of the low malt extract of Nobarb and the low values for its malt diastatic power and wort nitrogen content. Nobarb does not modify adequately and is classed as an inferior variety for malting.

Ottawa E 25.—Despite the high percentage of heavy grade kernels and the high kernel weight of Ottawa E 25, its starch content and barley extract are lower than those of O.A.C. 21. The supply of saccharifying enzymes appears satisfactory, though this may be due to its somewhat high barley nitrogen content; but proper malt modification is not obtained and Ottawa E 25 is seriously faulted in malt extract, diastatic power and wort nitrogen content. This is probably due to the rather large kernels of this variety, which as with Trebi, prevent rapid and uniform distribution of enzymes.

Plush.—This variety is no richer in potential extractives than O.A.C. 21 and it is definitely deficient in enzymatic properties. This is reflected in the malt by a lower extract than O.A.C. 21 together with low diastatic power and wort nitrogen content. Plush is, therefore, an inferior variety for malting.

Prospect.—This variety is similar to Ottawa E 25 in barley characteristics except that it is lower than the latter in nitrogen content and barley saccharifying activity. Malts made from it show deficiencies similar to those from Ottawa E 25.

Regal.—This variety is satisfactory in percentage of heavy grade kernels, kernel weight and nitrogen content, but deficient in extractives and enzymatic activity. Malts from Regal are characterized by low extract, diastatic activity and wort nitrogen.

Saskatchewan 264.—The major faults of this variety appear to be a low percentage of heavy grade kernels, (though it is satisfactory in kernel weight), and a tendency towards a deficiency in saccharifying enzymes. It appears equal to O.A.C. 21 in extractives, malt extract and wort nitrogen content, but because of the above noted deficiencies, it is not equal to the standard in malting quality. However, it is one of the better smooth-awned varieties.

University of Alberta 8.—This variety appears satisfactory with respect to percentage heavy grade kernels, kernel weight, nitrogen content and starch content. However, it is low in barley extract and saccharifying activity and does not modify adequately during the malting process. University of Alberta 8 does not appear promising as a malting barley.

Velvet.—The low values of this variety for barley extract and starch are reflected in the malt, and it is faulted in malt extract. However, Velvet appears to modify quite well and though not equal to O.A.C. 21 in malting quality it is one of the better smooth-awned varieties.

Wisconsin 38.—This variety is deficient in barley extractives and in barley enzymatic activity. These faults are more pronounced in the malt, which indicate poor modification. Wisconsin 38 is definitely one of the poorest varieties from the malting viewpoint.

York.—While the barley properties of this variety are fairly satisfactory, it appears to be deficient in growth activity and does not modify adequately during the malting process. York does not compare favourably with O.A.C. 21 in most properties and it is not regarded as promising.

TWO-ROWED ROUGH-AWNED VARIETIES

The two-rowed varieties of barley differ considerably in malting quality from the six-rowed varieties. The former have larger kernels and though they contain higher amounts of starch and other extractable compounds, they do not modify readily within the 6-day germination period used in Canada. In Europe, where two-rowed barleys are malted extensively, the environmental conditions tend to produce a large mellow kernel of very low protein content. Barley of this sort modifies well if grown slowly for a period of about 12 days. In Western Canada, Ontario and Quebec, which produce practically all of Canada's malting barley, the environmental conditions produce barleys of much higher protein content. Under these conditions only the six-rowed Manchurian type varieties produce barley from which good malt can be made. It is widely recognized that high protein content is undesirable in all malting

barleys, but it may be added that it is far more undesirable in two-rowed barleys than in six-rowed barleys of the Manchurian type.

Canadian plant breeders have wisely confined their activities to the production of better six-rowed malting varieties. However, in certain crosses a two-rowed variety has been used as one parent. Accordingly, it seems wise to put on record in this paper such information as is available on the malting qualities of Canadian-grown two-rowed varieties.

Hannchen.—Hannchen is used to some extent for malting in the United States and it appears to have met with favour under some conditions. For this reason, Hannchen may be used as a convenient standard for the two-rowed varieties. Hannchen is higher than O.A.C. 21 in starch content and barley extract, but lower that the latter in saccharifying activity and salt soluble nitrogen. Although Hannchen is higher than O.A.C. 21 in malt extract, it is not as high in this quality as might be expected in view of its difference from O.A.C. 21 in starch content, barley extract and kernel weight. This is without doubt due to the fact that a 6-day germination period is not long enough for adequate modification of a two-rowed variety. Bearing in mind the difference in rate of modification between Hannchen and O.A.C. 21 the two varieties are quite similar in most characteristics.

Charlottetown 80.—The barley properties of this variety are quite similar to those of Hannchen, although it is higher than the latter in barley nitrogen content. However, Charlottetown 80 does not modify as readily during the malting process as does Hannchen and it cannot be regarded as equal to the latter in quality.

Victory.—This variety is essentially similar to Charlottetown 80 in characteristics, though somewhat lower than the latter in barley nitrogen content, salt coluble nitrogen and wort nitrogen content. It is classed as inferior to Hannchen in malting quality.

TWO-ROWED SMOOTH-AWNED VARIETIES

Rex.—The percentage of heavy grade kernels for Rex is similar to that of Hannchen, but the former is higher than the latter in kernel weight and in nitrogen content. Despite its high kernel weight Rex is lower than Hannchen in extractives and these deficiencies are carried into the malt. Rex is not equal to Hannchen for malting purposes.

Sannalta.—This variety has exceptionally large kernels, but it is lower than Hannchen in starch content and in barley extract. It seems reasonably well supplied with enzymes and modifies fairly well, but as it is lower than Hannchen in malt extract it is not equal to Hannchen in malting quality.

SELECTION OF HYBRID MATERIAL

In the past two years the Malting Laboratory has made many tests on hybrid material and in future years many more hybrids will be ready for testing. The capacity of the malting equipment is limited to about

a thousand malts per year. This means that relatively few of each breeder's hybrids can be adequately tested in any one year. To provide the plant breeders with improved service, the malting staff has directed its effort to the prediction of malting quality from barley analyses. The determinations on the barley that appear useful are as follows: starch, barley extract, diastatic power and salt soluble nitrogen. To these may be added the customary determinations of nitrogen content, percentage heavy grade barley and thousand kernel weight. The quantity of barley required for these determinations is about 100 grams, less if single determinations are made, as compared with 550 grams for a single malting test. The barley tests may be used to replace the malting tests for preliminary selection of promising strains and the testing of these strains can be carried out at a much earlier stage of production than is possible by malting tests. A greater number of samples can be tested per year than can be tested by malting alone and it is also possible for plant breeders to make use of their local facilities for determining certain barley properties.

The selection of hybrids is carried out somewhat as follows. The plant breeder selects those hybrids having the agronomic qualities he desires, such as high yield, smooth awns, and resistance to rust. The selected strains are then examined and those with undesirable kernel characteristics eliminated. The standards for selection of promising hybrids varies according to parentage. Although a medium kernel size is desirable in the final product, the optimum kernel weight at any individual stage of a given program depends on the parentage of the strains and also on the other parent for the next cross.

The optimum nitrogen content at the various stages is more readily defined than the optimum kernel weight, and although definition in percentage is impossible, the optimum nitrogen content may be taken as equal to or somewhat lower than for O.A.C. 21 under the local environmental conditions. Low nitrogen content is desirable, but it must be borne in mind that a very low nitrogen content is often associated with low enzymatic activity.

The lines which remain after elimination on the basis of yield, agronomic characteristics, kernel type and nitrogen content, are then subjected to further examination in the laboratory. Estimates of the probable yield of malt extract can be made by determinations of barley extract or starch, and a good idea of the comparative enzymatic activities of the new lines can be obtained by determinations of salt-soluble nitrogen and activated diastatic activity. New materials which still seem promising after examination by these various methods are then promoted to more extensive field trials, subsequently to laboratory malting tests, and finally to commercial malting tests.

It is essential that there be close co-operation between malting chemists and plant breeders throughout the whole program. The former, without detailed information on the breeding program, may be inclined to dismiss as unpromising certain new lines which the plant breeder intends to cross with another variety having complementary faults and virtues. On the other hand, the malting chemist, with a detailed knowledge

of the properties of available breeding material, and some insight, however vague, into the delicate balance of properties which seems essential for adequate malting quality, should be able to make worthwhile suggestions from time to time. While these will deal principally with the particular methods which might be applied in segregating the better lines resulting from any given cross, it is not inconceivable that the chemist may also be able to make useful suggestions concerning the selection of additional parents for further crossing. This type of team-work has made rapid strides in Canada and still closer co-operation between malting chemists and plant breeders is developing steadily.

SUMMARY

It is pointed out that malting quality may be defined differently in different countries, and factors affecting the definition for Canadian barleys are considered. The problems which face Canadian plant breeders and cereal chemists, in collaborating to produce barleys of better agronomic and malting quality, are discussed in the light of recent researches. The authors record their opinions on the interpretation of analytical data on barley and malt, and a tentative definition of malting quality, applicable to Canadian barley, is developed.

In order to provide a ready reference for plant breeders seeking additional parent varieties for introduction into their breeding programs, the malting qualities of twenty-eight varieties are discussed, in general terms, with respect to physical characteristics of the kernel, potential extractable material and enzymatic activity. The use of barley analyses for predicting malting quality is outlined, together with ways in which various determinations can be used for selecting promising new hybrid lines.

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